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CHEMICAL ECOLOGY AND MANAGEMENT OF FOREST INSECT PESTS

NSERC Industrial Research Chair: Phase II

Third Annual Report

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EXECUTIVE SUMMARY

This is the third of five annual reports on Phase II of my Industrial Research Chair. The Chair research focuses on the chemical ecology and management of forest insect pests in western Canada. A major effort involves the use of coupled gas chromatographic-electroantennographic detection (GC-EAD) analysis to identify semiochemicals (message-bearing chemicals) that mediate the behaviour of terminal and woodboring weevils, bark beetles, ambrosia beetles, large woodboring beetles, and true bugs. The Chair philosophy is to take new discoveries into the field rapidly, and to work with industry to bring any new promising materials or methods to operational status with dispatch.

During the year ending on 30 September 1999, the Chair supported in whole or part 4 Postdoctoral Fellows or Research Associates, 4 Research Technicians, 4 Ph.D. Students, 6 Master of Pest Management (M.P.M.) Students, and 6 Research Assistants, One M.Sc. student and 4 M.P.M. students received their degrees during the past year.

Results of interest during the past year include:

1. discovery by GC-EAD analysis of a potential new pheromone in the white pine weevil, *Pissodes strobi,* that may also be involved in maintaining reproductive isolation from *P. schwarzi;*

2. capture of female *P. schwarzi* in pitfall traps baited with grandisol and grandisal, demonstrating that these compounds are sex pheromones in this species;

3. demonstration with the Douglas-fir beetle, *Dendroctonus pseudotsugae*, that repellency of non-host angiosperm bark volatiles lies in at least 3 functional groups, the alcohol and phenol group (benzyl alcohol, guiacol, (*Z*)-3-hexen-1-ol, and 1-hexanol), the aldehyde group (hexanal, (*E*)-2-hexenal, and nonanal, but not salicylaldehyde or benzaldehyde), and the spiroacetal conophthorin;

4. finding in contrast to point 3 (above) that attraction of the spruce beetle, *D. rufipennis,* to its aggregation pheromone is enhanced in the presence of a non-host angiosperm bark volatile

blend consisting of salicylaldehyde, benzaldehyde, nonanal, benzyl alcohol, guiacol, and conophthorin;

5. almost complete protection of lodgepole pines from attack by the mountain pine beetle, when pairs of trees (with an attractant bait suspended between them) were each double wrapped with bubble cap "chains" releasing the prototype operational repellent blend consisting of (*Z*)-3-hexen-1-ol, (*E*)-2-hexen-1-ol, benzyl alcohol, guiacol, benzaldehyde, salicyaldehyde, nonanal, verbenone and conophthorin;

6. in a study of con- and heterospecific communication in *D. ponderosae* and the pine engraver, *Ips pini,* discovery that 2-phenyl ethanol (produced by both species) inhibited the response of *D. ponderosae* to its aggregation pheromone, nonanal (produced by both species and by lodgepole pine) reduced the response of *I. pini* to its pheromone ipsdienol, and *exo-* and *endo-*brevicomin (produced by *D. ponderosae*) inhibited the response of *I. pini* to ipsdienol;

7. finding of no correlation between the size of the male *I. pini* or female *D. ponderosae* and the amount of aggregation pheromone produced, but a strong correlation between the size of male *D. ponderosae* and the amount of antiaggregation pheromone, suggesting that females that attract large males that can protect their territory have the advantage of being able to devote most of their metabolic resources toward reproduction;

8. demonstration of very strong host discrimination among 4 species of coniferophagous bark beetles in that *D. pseudotsugae* and *D. ponderosae* could be only slightly induced by attractive pheromone baits to attack the reciprocal non-hosts, lodgepole pine and Douglas-fir, respectively (in both cases unsuccessfully), and that neither *D. rufipennis* nor the western balsam bark beetle, *Dryocoetes confusus,* could be induced to attack the non-hosts "interior " fir or spruce, respectively;

9. progress in developing a generic repellent blend of non-host angiosperm bark volatiles consisting of benzyl alcohol, 1-hexanol, methyl salicylate and salicylaldehyde for 3 species of ambrosia beetle pests, *Trypodendron lineatum*, *Gnathotrichus sulcatus*, and *G. retusus*;

10. almost complete late-summer protection of pheromone-baited Douglas-fir logs from attack by *G. sulcatus* when the 5 m-long logs were treated with 6.75 m-long PVC tubes stapled in S-curves along the tops of the logs, and releasing the non-host volatile blend in point 9 (above);

11. partial resolution of species specific communication systems among 4 native *Trypodendron* species, in that *T. betulae* may employ an entirely new pheromone (tentatively identified as tetrahydro-2,2,6-trimethyl-6-vinyl-2H-pyran-3-ol) along with birch volatiles, and *T. retusum* utilizes (+)-lineatin along with the aspen volatile salicylaldehyde, but the conifer-infesting *T. lineatum* and *T. rufitarsus* both utilize (+)-lineatin and therefore must employ some other chemical(s) in unilateral or mutual inhibition of response;

12. demonstration of greatly increased catches of cerambycid and buprestid woodborers in traps with upright crossed vanes or drainpipes placed above a water-trapping surface, and partial conversion to an operational trap utilizing crossed vanes over a dry bucket with an internal flange to retain captured beetles;

13. discovery that three woodboring *Monochamus* spp. are attracted by a blend of strongly antennally-active bark beetle pheromones consisting of ipsenol, ipsdienol, verbenone and *exo*-brevicomin, suggesting that utilization of bark beetle pheromone baits in a cross-vane trap could be the basis for a new operational trapping system for large woodboring beetles in the future;

14. partial elucidation of a sex pheromone in the late-season cerambycid, *Xylotrechus longitarsus*, with the primary constituent being 2-pentanol and the possible involvement of 2 ketones and 2 aldehydes;

15. significant progress in dendrochronological analyses of the impact of past defoliation by the spruce budworm, *Choristoneura fumiferana*, on the growth and decline of white spruce in northeastern B.C., including a reciprocal relationship between decline of spruce growth and an increase in the growth of hardwoods during the past 2 outbreaks;

16. finding that prevalence of the poplar and willow borer, *Cryptorhynchus lapathi*, an introduced weevil from Europe, is strongly affected by adverse climatic conditions in certain

biogeoclimatic subzones in B.C., that the weevil has at least doubled its geographic and host ranges since the early 1960's, and that the weevil can have a very severe impact on the growth and form of individual trees, but that in no case is any *Salix* species threatened with extinction;

17. successful development and partial validation of an antibody-based test for detecting minute amounts of residual salivary enzymes in conifer seed emptied by the western conifer seed bug, *Leptoglossus occidentalis*, providing for the first time a means of distinguishing between naturally-aborted seed and seeds that are empty because of seed bug feeding; and

18. establishment of a standard protocol for testing single seed in a Western blot assay that accurately discloses specific salivary proteins left by seed bugs in empty seeds.

Productivity of the Chair research program is evidenced by the publication since 1 October 1996 of: 31 papers in refereed journals and the acceptance of 6 more in press; one chapter; 9 non-refereed papers; and the submission of a U.S. Patent application (not on FRBC-funded research). Thirty-five listed items document my active professional life, including numerous teaching and service roles.

The Chair is in a deficit financial position. Revenues in the year ending on 30 September 1999 totalled $577,338, unofficial expenditures totaled $626,745, leaving a deficit of $49,407. Recovery should occur in the next two years as expenditures decline with the completion of projects and the departure of graduating students.

ACKNOWLEDGMENTS

I thank the many academic, government and industrial colleagues who have collaborated with me or my students, or who have provided advice or some other type of assistance. I have endeavoured to include their input in the text of this report; I take full responsibility and apologize for any omissions. Maintaining a large, productive research program would not be possible without major funding, and I am most grateful to the three government agencies and 20 industries listed on the cover page for their generous support, and for trusting me to make decisions on research, personnel and administration that I feel will maximize the return on their investment. In this regard I especially thank my project administrators, Mr. Jean-Pierre Labelle of NSERC and Mr. Kevin Carvill, R.P.F. of the Science Council of B.C. for their administrative acumen and flexibility and the respect they have shown for the value of my research program.

TABLE OF CONTENTS

PAGE

I. INTRODUCTION 1

II. RESEARCH REPORT 2

A. TERMINAL AND ROOT COLLAR WEEVILS 2

B. BARK BEETLES 5

C. WOODBORING BEETLES (FRBC ref: #PA97511) 10

1. Ambrosia Beetles 11

2. Conifer-Infesting Cerambycid and Buprestid Beetles 14

D. WOODBORERS OF ANGIOSPERM TREES 20

E. IMPACT ASSESSMENT OF THE WESTERN CONIFER SEED BUG (FRBC ref. #PA97510) 21

F. PESTS OF CONIFER NURSERIES 25

III. EXTENSION 26

IV. PUBLICATIONS AND PATENTS (1 OCTOBER 1996 TO 30 SEPTEMBER 1999) 27

A. PAPERS IN REFEREED JOURNALS 27

B. CHAPTERS IN BOOKS 32

C. NON-REFEREED PUBLICATIONS 32

D. PATENT 33

E. LETTER TO THE EDITOR 33

TABLE OF CONTENTS

PAGE

V. PROFESSIONAL CONTRIBUTIONS (J.H. BORDEN, 1996-9) 34

VI. GRADUATES 39

VII. RESEARCH PERSONNEL 43

A. POSTDOCTORAL PERSONNEL 43

B. RESEARCH TECHNICIANS 44

C. PH.D. STUDENTS IN COURSE 45

D. MASTER OF PEST MANAGEMENT STUDENTS IN COURSE 46

E. RESEARCH ASSISTANTS 48

VIII. PHYSICAL RESOURCES 49

IX. FINANCIAL SUMMARY 50

A. REVENUE (1 OCTOBER 1998 TO 30 SEPTEMBER 1999) 51

B. EXPENDITURES (1 OCTOBER 1998 - 30 SEPTEMBER 1999) 51

C. CURRENT FINANCIAL POSITION 52

I. INTRODUCTION

This is the third Annual Report of the five-year Phase II of my NSERC Industrial Research Chair. The objectives of Phase II, as outlined in the proposal for renewal of the Chair were to:

1. use GC-EAD technology in collaboration with Dr. Gerhard Gries of SFU to identify compounds in the bark of at least 6 species of non-host trees that are potential repellents for 6 species of bark beetles, 2 species of terminal weevils, 3 species of ambrosia beetles and numerous species of cerambycid and buprestid woodborers;

2. use similar methodology to identify potential host attractants for terminal weevils and woodboring beetles;

3. conduct field experiments designed to test the ability of non-host volatiles to deter the above insects from responding to attractant-baited traps, and for host volatiles to attract terminal weevils and woodboring beetles;

4. determine the potential efficacy of non-host volatiles in protecting trees, stands and logs from attack by damaging insects;

5. work with industry in developing operational protocols for using repellent non-host volatiles in forest pest management;

6. work with industry to incorporate new strategies and tactics using attractive semiochemicals alone or in combination with repellents to manipulate pest insect populations;

7. continue to work with Dr. Gries and Dr. Keith Slessor of SFU to identify the pheromones of selected insect pests of forests, forest products, seed orchards and nurseries; and to

8. maintain a sufficiently large and flexible laboratory to enable rapid initiation of "on-demand" research as opportunities arise and demand is expressed by industry.

These objectives have been modified over the course of 3 years to place a renewed emphasis on attractant baits for weevils and large woodboring beetles. In general the original objectives are also being pursued, resulting in an expanded, multi-faceted research program.

This report contains the research components of the 6-month interim reports for two FRBC projects on woodborers (Section II, C) and seed bugs (Section II, E). It also encompasses the final report for the $75,000 contribution from FRBC (FRBC ref. #HQ96233-RE and SCBC ref. #FR-96/97-837) to the $300,000 NSERC CRD grant package that constitutes the 5-year stable funding base for the Chair.

II. RESEARCH REPORT

A. TERMINAL AND ROOT COLLAR WEEVILS

- Two years of postdoctoral research by Dr. Elizabeth Tomlin on the white pine weevil, *Pissodes strobi,* ended in May 1998 with her departure for the University of North Carolina at Greensboro. Although Dr. Tomlin, has been involved in a new research project since her arrival in North Carolina, and this year also gave birth to a son, she has been steadily working on finalizing the projects she began at SFU. One manuscript on chemical changes in weevil-resistant white spruce following wounding has been submitted to Tree Physiology, and another paper on the interaction between shading and induced resistance in Sitka spruce is in its second draft. Still to come are papers on fertilization, the ability of aphids and lygus bugs to induce traumatic resinosis, and the effect of wounding on the chemistry of Sitka spruce.

- MPM student Andrea Tanaka set up large field experiments at the B.C. Forest Service's Cowichan and Kalamalka Research Stations in the spring of 1999. These experiments were designed to test the effectiveness of host volatiles and the putative pheromones grandisol and grandisal as attractants for *P. strobi*, and to determine whether multiple-funnel traps could serve as effective replacements for the sticky pipe traps. Despite the timely deployment of the traps, and an exhaustive trap monitoring effort, almost no *P. strobi* were caught. This was probably because of the cold, wet-spring and early summer

in 1999, which (unlike the warm conditions in 1998) probably inhibited flight by the weevils. A major shortcoming of the sticky traps was their ability capture flying vertebrates, including an owl and a flicker, which had to be disposed of. As a solution to this problem, Mr. Ian Wilson of Phero Tech suggested that we test the "Tedder Trap", a commercially available device that captures pecan and citrus weevils climbing up from the ground, where they overwinter. Ms.Tanaka will pursue that suggestion next spring with *P. strobi*. We thank Drs. Ward Strong and Mike Carlson, Kalamalka, and Mr. Don Carson, Cowichan for assistance in accommodating this research on B.C. Forest Service premises.

- For many years, it has been suspected that some elusive pheromone component has escaped detection in *P. strobi*. This hypothesis has stemmed from the relatively poor activity of grandisol and grandisal, as opposed to its their level of activity in the related species *P. nemorensis*. Moreover, in work conducted over a decade ago in New York state, Dr. Tom Phillips found that combing *P. strobi* males with an attractive bait for *P. nemorensis* "blocked" the attractive response for the latter species. Could it be that the blocking factor had a dual function, acting as an intraspecific attractive pheromone, and as an interspecific repellent synomone, ensuring reproductive isolation? Yet, no suspect compound has ever been detected by conventional gas chromatographic (GC) analysis. Ms. Tanaka, along with another MPM student Ms. Elaine Goudie is further investigating this hypothesis. Following the suggestion of Dr. Harold Pierce, the plan is to capture volatiles from males of both species feeding on rolled oats. This will eliminate host volatiles that may confound the search. With the collaboration of Ms. Regine Gries, the captured volatiles will then be analyzed by coupled CG-electroantennographic detection analysis (GC-EAD) using the antennae of both sexes of *P. strobi,* as well as the antennae of *P. schwarzi,* a local weevil that like *P. nemorensis* must also maintain reproductive isolation from *P. strobi*.

- Preliminary results are exciting. Captured volatiles from *P. strobi* produce an unknown compound that excites the antennae of both sexes of both species, yet is present in such low amounts that it is undetectable by the flame ionization detector (FID) of the GC. This work is continuing, with the focus on obtaining enough of the unknown compound to identify, pursuing the reciprocal work with volatiles from *P. schwarzi*, and laboratory olfactometer bioassays with both species.

- As part of her MPM thesis research, Ms. Goudie is field testing grandisol and grandisal as potential pheromones for *P. schwarzi*. This experiment follows up earlier work by Dr. Lorraine Maclauchlan of the B.C. Forest Service, Kamloops Region, indicating that male *P. schwarzi* produce a sex pheromone, and collaborative GC-EAD analysis with Dr. Pierce and Ms. Gries demonstrating that male *P. schwarzi* produce the above compounds and that the antennae of both sexes respond to them. With the assistance of Dr. Maclauchlan, Ms. Goudie set up a randomized block field experiment in the Penticton Forest District using pitfall traps spaced at 5 m intervals in a lodgepole pine plantation infested with *P. schwarzi*. Over the course of the 1999 summer, traps baited with cut pine stems plus grandisol and grandisal captured 17 weevils, as opposed to 7 weevils in traps baited with cut stems plus male weevils, 4 weevils in traps baited with grandisol and grandisal, and 4 weevils in control traps baited with cut stems.

- In another component of her research Ms. Goudie is examining the potential of *P. schwarzi* as a silvicultural pest in a lodgepole pine stand subjected to thinning plus normal or severe pruning. Male/female pairs of weevils were caged in the summer of 1999 on the lower boles of trees with both pruning regimes, as well as on trees in control plots with thinning alone. These trees will be examined for weevil attack in 2000. In the same research site, Ms. Goudie is reconstructing the impact of the lodgepole terminal weevil, *Pissodes terminalis*, and western gall rust, *Endocronartium harknessii*, as pests that may have been accentuated by silvicultural treatment. Dr. Maclauchlan has facilitated Ms. Goudie's field research and is serving on her Supervisory Committee.

- Ms. Tanaka is developing a reference collection of *Pissodes* spp. using authentically-identified specimens returned to us by Dr. David Langor of the Canadian Forest Service, Edmonton. This collection is being used to identify weevils captured in 1999 and to re-evaluate identifications of weevils from 1998. The collection at the Canadian Forest Service's Pacific Forestry Centre in Victoria is also used as a reference source.

- Ms. Tanaka presented a paper on *P. strobi* chemical ecology to the joint meeting of the Western Forest Insect and Forest Pathology Work Conferences in Breckenridge, Colorado in September 1999.

B. BARK BEETLES

- Ph.D. student Dezene Huber completed a large number of field trapping experiments in the summer of 1999 designed to tease out the bioactivity of antennally-active non-host angiosperm bark volatiles against: the Douglas-fir beetle, *Dendroctonus pseudotsugae* (7 experiments); the mountain pine beetle, *D. ponderosae* (4 experiments); the spruce beetle, *D. rufipennis* (2 experiments); the western balsam bark beetle, *Dryocoetes confusus* (3 experiments); and the pine engraver, *Ips pini* (5 experiments). Sexing and counting of captured beetles is still in progress, and the cool weather in 1999, resulting in poor catches in some cases, may necessitate repeating some experiments next summer.

  Nonetheless, results for the Douglas-fir beetle (which flies in early spring) indicate that repellent activity is found in the alcohol and phenol group (benzyl alcohol, guiacol, (*Z*)-3-hexen-1-ol and 1-hexanol), the aldehyde group (hexanal, (*E*)-2-hexenal and nonanal, but not salicylaldehyde or benzaldehyde), and conophthorin. The greatest reductions of catches (94 and 92% for males and females, respectively) were achieved when all those groups of non-host volatiles were added to pheromone-baited traps. In contrast, for the spruce beetle a blend of compounds comprising salicylaldehyde, conophthorin, guiacol, nonanal, benzaldehyde and benzyl alcohol actually enhanced responses (3.9- and 4.8-fold for males and females, respectively) to pheromone-baited traps. Further research is required to resolve this anomaly. It is possible that we will find a useful new attractant for the spruce beetle. On the other hand the results to date with the Douglas-fir beetle and the mountain pine beetle indicate real potential for operational exploitation of the potent non-host volatile repellent blends. We thank Messers. Don Wright, B.C. Forest Service, 100 Mile House District, and Ed Senger, Lillooett District, for assistance in finding and approving trapping sites for this research. A paper in preparation for submission to Chemoecology on the detection of antennally-active compounds in the bark volatiles of 6 species of angiosperm trees in nearing completion.

- Conophthorin is a generally repellent pheromone in a number of cone and twig beetles. We have also found it in the bark of maples, poplars and aspens, and it constitutes 12% of the bark volatiles of paper birch in B.C. A manuscript demonstrating the repellency of conophthorin released at 3 mg/24 h (but not at 0.3 mg/24 h) to *D. pseudotsugae*,

Dryocoetes confusus, and *Ips pini*, but not to *D. rufipennis*, was submitted to the Canadian Entomologist in December 1988. Although favourably reviewed, the manuscript was returned with the suggestion that further experimentation be done with *D. confusus* because of low and inconsistent trap catches. Additional experiments were set up in 1999, but the results have not yet been analyzed. This project builds on our earlier demonstration that conophthorin alone is repellent to *D. ponderosae*, and indicates that it is a general, but not universal, repellent for aggressive coniferophagous bark beetles.

- The most exciting results with non-host volatiles were achieved by Mr. Huber in a tree protection experiment conducted at the University of British Columbia's Alex Fraser Research Forest near Williams Lake B.C. This work was facilitated by Mr. Ken Day and Ms. Claire Trethewy. In previous experiments, the non-host volatiles had been deployed from devices stapled adjacent to attractive baits on the tree. Although they effectively challenged beetles that could have responded to the baits, the challenge was to a single point source. The question remained as to whether the non-host volatiles could protect trees from attack if beetles drawn into the vicinity were free to attack anywhere on the bole of a tree treated with devices releasing non-host volatiles. This question was addressed by hanging attractive pheromone baits mid-way between 25 pairs of lodgepole pines. Both trees in the pair were then treated in late June 99 with a double-wrap of 2 chains of bubble caps (Phero Tech. Inc.) releasing the antiaggregation pheromone verbenone, the repellent kairomone conophthorin, and a blend of natural alcohols and aldehydes including: (*Z*)-3-hexen-1-ol, (*E*)-2-hexen-1-ol, benzyl alcohol, guiacol, benzaldehyde, salicylaldehyde, and nonanal. (This is our tentative operational treatment blend for *D. ponderosae).* Twenty-five pairs of control trees received only attractive baits.

  The results were most encouraging. Twenty-one of the 25 pairs of control trees were mass-attacked; only three of the pairs of treated trees were attacked.

- A second experiment, with no attractive baits, was set up with 60 pairs of trees in an "explosive" infestation near 100 Mile House. One tree in each pair received the non-host volatile/antiaggregation pheromone bubble-cap wrap as above, and the other served as an untreated control. In this case 11 of the 60 control trees were attacked, as were 6 of the 60 experimental trees. It is possible that an attack front that surrounded the six treated trees

simply overwhelmed the treatment. Alternatively, we hypothesize that attractive baits, as in the first experiment, may be required to "switch" the beetles from a random search mode to a non-random mode in which they become more responsive to repellent treatments. Thus repellent treatments may be most effective when an attractant-baited trap or tree is nearby. We are exploring this possibility with Phero Tech. We are grateful to Messers Don Wright of the B.C. Forest Service, 100 Mile House District, and Lennart Holm, Ainsworth Forest Products Ltd. for assistance in arranging for the research site to be reserved until after the experiment was completed.

- Mr. Huber presented some of his results at the December 1998 meeting of the Entomological Society of America in Las Vegas, Nevada. He received the President's Prize for best student paper in his category.

- Over the past year M.Sc. student Deepa Pureswaran completed her research, and in July 1999 and defended her thesis on pheromone production dynamics and interspecific communication in the mountain pine beetle and the pine engraver. Her thesis contained a number of pertinent and potentially useful findings. Among the captured volatiles from both sexes of *D. ponderosae* and *I. pini* in three phases of attack (emerged beetles, first-attacking sex alone in the bark, and both sexes paired in the bark) there were 10 compounds detected by GC-EAD analysis that had not been tested for behavioural activity. Field experiments disclosed no new attractants, but 4 compounds with repellent activity as follows.

  1) 2-Phenyl ethanol produced by both species inhibited the response of *D. ponderosae* to its aggregation pheromone and therefore functions as an antiaggregation pheromone for *D. ponderosae* and as an interspecific synomone (of benefit to both species) when released by *I. pini.*

  2) Nonanal, detected in the volatiles of lodgepole pine and in both beetle species, significantly reduced the attraction of *I. pini* to ipsdienol. Thus, it would serve as an antiaggregation pheromone for *I. pini* and as a synomone when released by *D. ponderosae.*

3) *exo-* and *endo-*Brevicomin which are produced by *D. ponderosae*, significantly reduced the response of *I. pini* to ipsdienol, indicating their newly discovered function as synomones for both species.

Nonanal is already known as an antiaggregant for some *Dendroctonus* spp. (see above), and it is now shown to have the same property for an *Ips* species. 2-Phenyl ethanol is now a candidate for addition to operational repellent blends for tree-killing bark beetles, and the brevicomins could be added to other antiaggregants used to treat slash to prevent build-up of *I. pini* populations that could threaten residual trees after spacing operations.

Surprisingly Ms. Pureswaran found no correlation between beetle size and the production of aggregation pheromones, primarily because a few beetles would characteristically produce large amounts of attractive pheromone, and the remainder very little. These latter beetles might employ a "sneaker" strategy, whereby they avoided the metabolic cost of pheromone synthesis, and exploited the excess potential mates attracted by the big time producers. In contrast a high correlation was found between male size and production of antiaggregants in paired *D. ponderosae*, and between female size and male antiaggregant production. These relationships indicate that pheromone-mediated intraspecific resource partitioning, not the production of aggregation pheromone, is a major factor in reproductive success. Mate choice may involve other non-pheromonal cues such as gallery length and stridulation. Manuscripts on this research are in preparation for submission to the journals Chemoecology, Journal of Behavioural Ecology, and Environmental Entomology.

- Ms. Pureswaran presented the partial results of her research at two conferences, the 1998 annual meeting of the Entomological Society of America in Las Vegas, Nevada, and the joint meeting of the Western Forest Insect and Forest Pathology Work Conferences in Breckenridge, Colorado in September 1999.

- In 1999, Ms. Pureswaran started her Ph.D. research on the chemical ecology involved in host selection, non-host avoidance, and heterospecific chemical communication in *D. ponderosae, D. pseudotsugae, D. rufipennis* and *Dryocoetes confusus*. These are the principal tree-killing bark beetles in B.C. They respectively infest lodgepole pine, Douglas-fir, interior spruce and subalpine (interior) fir. Bark/wood and foliage samples from all

host species have been field collected, and volatiles captured on Porapak Q. As the bark beetles become available from periodic field collections, the volatiles are being subjected to GC-EAD analysis by Ms. Regine Gries. In addition, for all 4 species of bark beetles, the captured volatiles from emergent beetles, the first-attacking sex alone in the bark, and both sexes paired in the bark are being analyzed by GC-EAD against the antennae of both sexes of all 4 species. The results of this exhaustive analysis should elucidate in part in the vast potential for chemically-mediated behaviour by these bark beetles. In addition, they should yield a fair number of new compounds for further behavioural research.

- As part of her studies on the mechanisms of host specificity, Ms. Pureswaran conducted 4 experiments in 1999 in which each of the 4 species of bark beetles was challenged to orient toward and attack the most common non-host conifer in its habitat. All four species were captured on wire mesh sticky traps stapled to the bole of non-host trees. Douglas-fir beetles were induced by frontalin baits to attack lodgepole pine, and mountain pine beetles were induced by *trans*-verbenol and *exo*-brevicomin baits to attack Douglas-fir. In both cases the attack was at very low levels, and in no case was it successful. Spruce beetles could not be induced by frontalin baits to attack subalpine fir, nor could western balsam bark beetles be induced by *exo*-brevicomin baits to attack spruces. These results demonstrate a very high degree of host specificity amongst this bark beetle guild, but unlike the apparent long-range detection and avoidance of non-host angiosperms found by Mr. Huber, it appears that detection of non-host conifers may occur at close range. This research was done in cooperation with Mr. Don Wright, B.C. Forest Service, 100 Mile House District, Mr. Lennart Holm, Ainsworth Forest Products Ltd., and Mr. Bob Foster, Tolko Forest Products Ltd.

- MPM student Alexander Gustafsson has completed two identical large field experiments testing sequential baiting for containment and concentration of mountain pine beetle infestations. One experiment was conducted near 100 Mile House and was facilitated by Mr. Lennart Holm of Ainsworth Forest Products Ltd, and Mr. Don Wright of the B.C. Forest Service, 100 Mile House District. The other was done on Red Plateau near Kamloops, and was facilitated by Mr. Tom Lewis, B.C. Forest Service, Kamloops District, and Mr. Ed Murray and Ms. Kaitlin Powell, Tolko Industries Ltd., Louis Creek, B.C.

Each experiment had three 16 ha blocks spaced 200 m apart in currently-infested stands. One block was treated in conventional manner, with 64 trees on 50 m centres baited in June, 1999. The second and third blocks were treated similarly, except that half and two thirds of the baits were withheld in the June baiting. A second baiting at the start of August completed the treatment for the second block and left one third of the baits still to be placed in the third block. These were affixed on the remaining bait trees in mid-August. All bait trees, as well as those within 5 m of the bait trees, were assessed for attack at two-week intervals beginning at the start of August and ending in mid-September. In late September to early October, all 6 blocks were 100% cruised, and the locations of all red- and green-attacked trees were mapped. Flight by *D. ponderosae* was monitored weekly throughout the flight season in 4 multiple-funnel traps per experiment. The data will not be completely analyzed for some time, but the impression gained during the assessment was that baiting twice was the most effective treatment.

- MPM student Nicole Jeans-Williams defended her thesis on determining the preferred tree bait for the western balsam bark beetle. She presented her results at the annual meeting of the Entomological Society of America in Las Vegas, Nevada in December 1998. In the summer of 1999 she conducted experiments evaluating the role of *exo*-brevicomin in the chemical ecology of a secondary spruce bark beetle, *Ips tridens*. Ms. Jeans-Willams is now a forest health consultant in Salmon Arm, and is working on two manuscripts from her thesis, to be submitted to refereed journals.

- Also defending MPM theses in the past year (both in December 1998) were Messers. Leroy Harder and Matthew Greenwood. Mr. Harder's work on baiting for *D. confusus* in alternative silvicultural systems is being prepared for a B.C. Forest Service Research Note, and Mr. Greenwood's results on co-baiting for *Dendroctonus rufipennis* and *Dryocoetes confusus* are in press in the Canadian Journal of Forest Research.

C. WOODBORING BEETLES (FRBC ref: #PA97511)

This project has been wholly funded by Forest Renewal B.C. since 1 April 1997, and is at the mid-year point of the third of five years. Two main insect targets of this research are ambrosia

beetles that cause well over $100 million in damage to B.C. timber each year, and the large woodboring beetles in the families Cerambycidae and Buprestidae that cause $44 million in damage to the interior B.C. lumber industry, and cause similar damage throughout the rest of Canada. The applied aspects of the ambrosia beetle sub-project are under my primary direction with operational management by Research Technician Leslie Chong. A more basic project that could have intriguing practical spin-off is being conducted by Ph.D. student Susanne Kühnholz. The woodborer sub-project has been run by Dr. Roy McIntosh who joined my laboratory as a Postdoctoral fellow in June 1997, but he will leave SFU in January to take on the job of Forest Insect and Disease Specialist for the province of Saskatchewan.

Dr. McIntosh served as the day-to-day supervisor of M.P.M. student Jeremy Allison, who is working on a component of the large woodborer study for his thesis research; because of his extensive knowledge of terminal weevil behaviour and ecology, Dr. McIntosh has had an additional role as advisor to our weevil project. We are seeking a replacement for Dr. McIntosh as this time.

1. Ambrosia Beetles

- The quest continues for a generic repellent for 3 main pest species of coniferophagous ambrosia beetles, the striped ambrosia beetle, *Trypodendron lineatum*, *Gnathotrichus sulcatus* and *G. retusus*. Previous reports documented research on coastal *T. lineatum*, reporting the moderate repellency of benzyl alcohol and 1-hexanol, the inability of this blend released at 2 m intervals from bubble caps to deter attack on logs, and more recent research that showed a strong repellency to a binary blend of methyl salicylate and salicylaldehyde. Research in 1999 focussed on comparing these two repellent blends alone and combined on coastal *T. lineatum*, and extending the research to cover the two *Gnathotrichus* spp.

  These experiments demonstrated 82.5 and 81.6% reduction of *T. lineatum* trap catches for males and females, respectively, when the quaternary blend was released from lineatin-baited traps, and a 59.2% reduction in catches of female *G. retusus*. Results for *G. sulcatus* are not yet available, but experiments in 1998 with methyl salicylate and salicylaldehyde mixed with a blend of a 6-carbon green leaf alcohols showed very high

repellency. It may yet be necessary to use a more complex blend, e.g. with nonanal added, but we decided to push ahead with a late-summer log protection experiment that gave cause for optimism (see below).

- In August 1999 we approached Mr. Martin Buchanan of Canadian Forest Products Ltd., Agassiz, B.C. for assistance in testing the efficacy of the 4-component generic blend in deterring attack by ambrosia beetles on vulnerable logs. Mr. Buchanan had been a pioneer nearly 2 decades previously in transferring trapping technology for ambrosia beetles into the industrial setting. The target in this case was *G. sulcatus*, which has a late-summer to early-fall flight, when other 2 species have stopped flying.

  Ten freshly-felled 5 m long Douglas-fir logs, 35.5-54.5 cm diam., were placed in the forest margin of a newly-cleared right of way. On 9 August, I and Ms. Chong baited each log with a sulcatol bait to induce the attack by *G. sulcatus*. Half of the logs also were treated with a 6.75 m-long PVC tube, filled by Dr. Pierce with a non-host volatile blend of benzyl alcohol, 1-hexanol, methyl salicylate and salicylaldehyde, and stapled in S-curves to the top third of the log.

  Each log was visually inspected on 2 September. At this time 4 of the 5 control logs were attacked by beetles verified to be *G. sulcatus*; three of these logs had many new attacks. One of the logs treated with non-host volatiles had one attack. On 15 October the attacks on the exposed surface all 10 logs were counted. There was a mean of 68.0 attacks per log on the control logs and 2.2 per log on the treated logs. We are excited by this promising result, and plan further experiments with *T. lineatum* and both *Gnathotrichus* spp. in the spring of 2000.

- In 1998-1999, Ph.D. student Susanne Kühnholz continued her research on the chemical ecology of the 4 native *Trypodendron* spp. in B.C. In collaboration with Dr. Pierce and Ms. Gries, Ms. Kühnholz obtained evidence on pheromone production from GC-EAD analysis of captured volatiles from field-collected beetles. It now appears that *T. lineatum*, *T. rufitarsus* and *T. retusum* all utilize (+)-lineatin as their aggregation pheromone. Species-specificity between the first two species, which inhabit conifers, and *T. retusum*, which attacks primarily trembling aspen, *Populus tremuloides*, appears to be mediated by

the host volatile salicylaldehyde. In one field experiment with multiple-funnel traps, *T. retusum* responded best to lineatin plus salicylaldehyde (54 beetles), with 2, 6, and 1 beetles being captured in traps baited with lineatin alone or salicylaldehyde alone, or unbaited traps, respectively. In contrast, *T. lineatum* responded to the same 4 treatments with 55, 1,579, 4, and 7 beetles captured, respectively. There is a slight but very incomplete temporal separation between the flight of *T. rufipennis*, which flies very early in the spring, and *T. lineatum*, which begins to fly somewhat later and extends its flight long into the summer. Therefore, Ms. Kühnholz hypothesizes that there is also a semiochemical-mediated unilateral or mutual inhibition between these species, and plans to investigate this hypothesis in 2000.

Trypodendron betulae, on the other hand, appears to utilize a completely different pheromone, tentatively identified as tetrahydro-2, 2, 6-trimethyl-6-vinyl-2H-pyran-3-ol. This pheromone may be synergized by host volatiles, e.g. conophthorin, to which there is a strong antennal response. These results suggest that molecular genetics studies, now in progress with Dr. Bernie Crespi of the Department of Biological Sciences at SFU, will reveal that *T. betulae* is distantly related to the other 3 species, which in turn are closely related. A busy field season is planned for 2000. Research in 1998-1999 in this project was aided by Mr. Howard Norman, Supervisor of Golf Course Operations, Fraserview Golf Course, who provided sites for research on *T. betulae*, and Ms. Susan Leech, Forest Science Officer of UBC's Malcolm Knapp Research Forest in Maple Ridge, B.C., where the field experiment on *T. retusum/T. lineatum* was conducted.

- Ms. Leslie Chong completed a third year of season-long field trapping for *T. lineatum, G. sulcatus* and *G. retusus* at UBC's Malcolm Knapp Research Forest. With almost weekly collections, this study will facilitate accurate timing of both future experiments and operational treatments. In collaboration with Dr. Lee Humble of the Pacific Forestry Centre, Canadian Forest Service, Ms. Chong is continuing to monitor in these and other traps for the presence of several species of exotic ambrosia beetles, that may be moving from port areas (where they were probably introduced in dunnage) into our native forests.

2. Conifer-Infesting Cerambycid and Buprestid Beetles

- We are well on the way to designing a better trap for operational use against woodboring beetles. This trap for will eventually replace Phero Tech's multiple-funnel trap, which is excellent for bark and ambrosia beetles, but is suboptimal for trapping woodboring beetles, and in very large infestations is readily saturated. Following the lead of Dr. Peter de Groot of the Canadian Forest Service, Sault Ste. Marie, Ontario, who used a water-filled Rubbermaid dish-pan, we used Rubbermaid tote boxes (#2212), 30 x 2.5 x 35 cm filled ca. one-third with water, with a dash of detergent to break the surface tension so trapped beetles would be readily immersed and killed. We tested tote boxes alone, tote boxes with a 1.5 m-high black-painted drainpipe standing in the water, black Plexiglas cross vanes standing 1.5 m-high in the water, and a "stack" of 3 bottomless flower pots, of increasing top diameter (20, 25, and 30 cm, upper to lower, respectively) suspended over the water. Each trap was baited with α-pinene and ethanol. All traps were constructed by Research Technician Pete Katinic, who also assisted in the field experiments. Ten replicates of each type of trap were tested in two locations, Gorman Bros. Sawmill, Westbank, B.C. from 16 June to 7 October 1999, and Vanderwell Contractors Ltd., Lesser Slave Lake., Alberta from 26 May to 1 August 1999. Captured insects were collected weekly.

  Trap catches were substantial in both locations, and are still being analyzed for catches of major targets, e.g. *Monochamus* spp., as well as for seasonal trends and instances of range extensions or the occurrence of introduced species. Nonetheless, visual inspection of trap contents showed very clear superiority of all 3 new trap types over the multiple-funnel traps or the "unadorned" tote boxes, and also a clear ranking of superiority, with crossed vanes on top followed by drainpipe or flower pot accessories with the tote boxes. Further encouragement comes from Dr. de Groot in Ontario who found very similar results using our trap designs adapted to a smaller catching receptacle.

  In this study our work at Gorman Bros. sawmill was facilitated and aided by Messers. Nick Arkle, Woodlands Manager; Howard Fenton, Mill Manger; Kerry Rouck, Total Resource Planning Forester; and Al Springer, Construction Foreman. The research at Vanderwell Contractors' mill site in Lesser Stave Lake was coordinated by Mr. Bob Setter of Bugbusters Pest Management, Prince George, B.C. (Bugbusters is expanding its

operations into Alberta), and was facilitated by Messers. Scott Formaniuk, Silvicultural Forester, and Al Morgan, Log Yard Manager.

- The cross vane wet trap represents a major improvement over the multiple-funnel trap or the dish-pan trap (affectionately dubbed the "Peter-pan" trap after Peter de Groot). However, its deficiencies include: the need for water and detergent; the unfortunate capture of small mammals and birds; the surprising ease with which the tote boxes move in high winds and develop punctures; and the stinking mess of captured insects that must be retrieved from the water.

  Therefore in late summer we developed, tested and partially reconstructed a prototype operational trap. This trap has lightweight plastic cross-vanes suspended over a dry bucket with a 360° flange at the top to prevent escape of captured beetles, eliminating the need for water. Although captured beetles are still being counted, and the prototype trap did work, the cross-vane wet trap was superior. Moreover, as constructed it was unstable in the wind and was even disassembled in the strong wind where it was tested in Weyerhaeuser Canada's dryland sort at Okanagan Falls, B.C. Were are grateful to Mr. Jay Mervyn, Log Yard Supervisor, for his help in this and other experiments at Okanagan Falls.

- A second major advance in woodborer trapping technology in 1998-1999 was MPM student Jeremy Allison's discovery that *Monochamus* spp. (and possibly other cerambycids and buprestids) respond to bark beetle pheromones. This line of research was not even dreamed of when we started this project in 1996. It arose from Mr. Allison's inventive mind during an enforced hiatus, when we ran out of beetles with which to conduct research on non-host volatiles during the hot, dry summer of 1998. He hypothesized that bark beetle pheromones function as indicators of potential woodborer habitat and consequently that woodborers may respond to them much like bark beetle predators respond to bark beetle pheromones. GC-EAD analysis by Ms. Regine Gries identified 4 pheromone components (ipsenol, ipsdienol, verbonone, and *exo*-brevicomin) from sympatric bark beetles that were strongly antennally active for *Monochamus clamator, M. scutellatus,* and *M. obtusus,* and five components (frontalin, 3-methycyclohexen-2-one (MCH), *endo*-brevicomin, and *cis*- and *trans*-verbenol) that were weakly active.

In a randomized block trapping experiment, with 25 replicates at Weyerhaeuser Canada's dryland sort at Okanagan Falls B.C. and 15 replicates at Gorman Bros. yard at Westbank, B.C., the strong and weak blends, alone and together, in combination with a 9-component monoterpene blend (see next section) were tested against the host blend alone (positive control) or unbaited traps (negative control). The results were striking. For all three *Monochamus* spp., the only treatment that resulted in significantly more captured beetles than unbaited control traps was the combination of the "strong" blend plus host volatiles! In Ontario, Dr. Peter de Groot ran the same experiment, apparently with similar results. Captured insects from a repeat of this experiment in Tackama Forest Products' (a Slocan company) dryland sort and mill yard at Fort Nelson, B.C. are still being processed. Similarly, identification and counting of captured insects is ongoing for two experiments run without unbaited controls at Millar Western Forest Products' log yard, Whitecourt, Alberta, and the mill site of Blue Ridge Lumber Ltd., also in Whitecourt, Alberta. The latter three experiments were coordinated by Mr. Setter of Bugbusters, with on-site liaison provided by Messers. John Pineau, Biologist, and Brain Davies, Log Yard Supervisor, respectively.

Proceeding logically, Mr. Allison then tested traps baited with the strong and weak pheromone blends alone and together against unbaited traps, eliminating the host volatile treatment. This experiment was run with 15 replicates at Ainsworth Forest Products' Exeter Division at 100 Mile House and 15 replicates at the Chasm Division in Chasm, B.C., with assistance from Mr. Ken Veilleitte, Log Yard Supervisor. Only *M. clamator* and *M. scutellatus* were present, but females of both species were present, in response to the strong blend in significantly greater numbers than to the unbaited control traps, demonstrating attraction to bark beetle pheromones in the absence of host volatiles.

Again proceeding logically, two additional experiments were set up. The first tested the individual components of the strong pheromone blend with host volatiles, the complete blend with host volatiles, and a host volatile control (4 replicates at Weyerhaeuser's sort at Okanagan Falls and 3 replicates at Gorman Bros. mill in Westbank). The second experiment did the same for the components of the weak blend, although *cis*- and *trans*-verbenol were tested together, as were *exo*- and *endo*-brevicomin (8 replicates on

Ainsworth's premises at 100 Mile House and 8 more at Chasm). Captured beetles from these experiments are still being processed.

In all of the above research we opted to cover a wide geographic area to provide an optimal chance of getting some (any) results. Experiments in 2000 will be more restricted in time if not in location, and will focus on defining which of the strong blend and host components are needed to provide optimal attraction, and on evaluating the combined effect of improved traps and baits over the present trapping system.

- Extensive testing by Dr. McIntosh and Mr. Katinic designed to produce a more attractive host blend than the currently used blend of α-pinene and ethanol continued in 1998-1999. Additional potential components were selected on the basis of GC-EAD analysis by Ms. Gries in 1996-1998. One 9-component monoterpene blend was put together specifically for *Monochamus* spp., and another for buprestids. Also tested was a secondary 6-component blend of other compounds that were generally antennally active. Several field trapping experiments tested these blends at three sites: Laluwissen Creek near Lytton, with the aid of Mr. Ed Senger, B.C. Forest Service, Lillooet District; Weyerhaeuser Canada's mill yard at Okanagan Falls; and Tolko Industries' mill yard, Lavington, B.C. with the aid of Mr. Brain Eso, Mill Yard Supervisor.

  In no case did either monoterpene blend, the secondary blend or both together significantly improve catches over α-pinene plus ethanol. However, the catches from two experiments are yet to be processed, as are the catches from a companion test of the *Monochamus* monoterpene blend by Dr. de Groot in Ontario. We tentatively conclude that there is great redundancy in the natural host kairomone system of polyphagous woodborers. The essential ingredients appear to be at least one conifer signal (α-pinene will probably suffice), and one signal (ethanol) that anaerobic metabolism is occurring, i.e. the host is stressed and susceptible. It is unlikely that we will continue this line of research in years 4 and 5 of the project.

- Pheromone candidates for zebra beetles, *Xylotrechus longitarus*, a very damaging late-summer woodborer, were also tested by Dr. McIntosh and Mr. Katinic. These experiments utilized two additional field sites, Weyerhaeuser Canada's mill yard at

Princeton, B.C., with the assistance of Mr. Dave Logan, Mill Yard Supervisor, and Riverside Forest Products' dryland sort and storage yard at Bear Creek near Kelowna, B.C., with the aid of Mr. Gary Grail, Log Yard Supervisor. The principal pheromone candidate established by GC-EAD and GC-MS analyses by Ms. Gries, is 2-pentanol. In the first experiment 2-pentanol alone increased the catches over those unbaited traps by 1.3 times. Correspondingly, 2-pnetanol also increased catches to α-pinene and ethanol 1.4 times over those in traps baited with α-pinene and ethanol alone. Other experiments were run, with results not yet available. One tested a candidate aldehyde blend (octanaol plus nonanal) and also a ketone blend (2-octanone plus 2-decanone) in combination with α-pinene and ethanol. Another tested 2-pentanol plus the aldehyde and the ketone blends with and without α-pinene and ethanol, and lastly tested the above blends with α-pinene and ethanol. If promising results are found, we will begin next summer to develop an operational trapping protocol specifically targeted for *X. longitarsus*.

- MPM student Ms. Jennifer Burleigh completed her second summer of research in 1999 on forest decline following extensive defoliation by spruce budworm, *Choristoneura fumiferana*, in the Liard River drainage. This project is being conducted in collaboration with Mr. Setter of Bugbusters, and Dr. René Alfaro of the Canadian Forest Service, Pacific Forestry Centre, Victoria, B.C., and is facilitated by Mr. John Dymond, Senior Woodland Planner, Tackama Forest Products. The project arose because of the alarm raised by woodborer attack on defoliated trees that appeared to be recovering, and has evolved into a study on the woodborers of northeastern B.C., as well as a dendrochronological analysis of the impact of defoliation.

  Laborious processing of trap catches from 1998 has revealed over 50 species of woodboring insects in the Liard/LaBiche area, including a new location record for *Buprestis laeviventris*. We are awaiting return of many specimens sent for identification to taxonomists in both Canada and the USA. An experiment was setup in 1999 to monitor emergence from bolts cut from different heights from white spruce trees that had been attacked by woodborers over the last 4 years. Evaluation of this experiment will continue in 2000. Ms. Burleigh has built chronologies for 7 drainages in the Fort Nelson Forest District, revealing 2 spruce budworm outbreaks in the past century in southern drainages, and 4 outbreaks in northern drainages. During the past 2 outbreaks, decline in the growth

of the white spruce was associated with a corresponding increase in the growth of paper birch and trembling aspen. Ms. Burleigh plans to write her MPM thesis in the spring of 2000 on her dendronological study. The woodborer research will be written up for publication when all results are compiled.

- Work has continued on our woodborer reference collection. We have made great progress in the diversity, quality and range of specimens in the collection. In particular we have collected some excellent specimens of cerambycids such as *Ergates*, *Prionus*, and *Tetropium* spp., and high quality specimens of hymenopteran woodborers, *Urocerus*, *Sirex*, and *Xeris* spp. This is a working collection, in constant use for verification of the identity of captured beetles.

- In addition to working closely with potential users of our new technology, we were engaged in 1999 in two major extension activities specifically related to woodborers. The first was a strategic meeting at Phero Tech's premises in Delta on 8 September, 1999 attended by me, Dr. McIntosh and Mr. Katinic from SFU, and by Messers, Jerry Carlson (Technical Services Manager), Steve Burke (General and Sales Manager), Ian Wison (Manager, Interior B.C.), Troy Kimoto (Pest Management Specialist) of Phero Tech. Discussions focussed on our trap design and bark beetle pheromone research, and facilitation of technology transfer. It was agreed it was better to hold back for year on changing the design of operational traps until, but to consider adding bark beetle pheromones to the baits as early as the 2000 trapping season.

  The second event was a visit arranged at SFU on 22 September by Mr. Paul Newman of the Council of Forest Industries of B.C. for Mr. Bill Crowe (Entomologist) and Dr Emmanuel Mireku (Plant Pathologist) of the Australian Quarantine Inspection Service (AQUIS). Mr. Jerry Carlson represented Phero Tech at this meeting, and our group was represented by Dr. Rory McIntosh, Mr. Jeremy Allison, Ms. Susanne Kühnholz and Ms. Jennifer Burleigh. The Australians have become increasingly concerned about the possibility of introduction of exotic woodborers, and sought reassurance, not only that our phytosanitary procedures are sound, but also that we are doing research that may be of some use. Roundtable sessions were held, including discussions between AQUIS representatives and students. The site visit included a tour of our facilities, in particular the

reference collection, rearing facilities and the GC-EAD laboratory. It was a very satisfactory meeting.

- Mr. Allison presented his preliminary results at the joint meeting of the Western Forest Insect and Forest Pathology Work Conferences in Breckenridge, Colorado in September, 1999. Ms. Burleigh was even busier, presenting her research in poster form, not only at Breckenridge, but also at the International Union of Forest Research Organizations meeting on Population Dynamics and Ecology of Forest Defoliating Insects in Victoria, B.C. in August, 1999. By request, her poster is now displayed at the B.C. Forest Service Regional Office in Prince George.

D. WOODBORERS OF ANGIOSPERM TREES

This project, which has focussed to date on an exotic weevil, the poplar and willow borer, *Cryptorhynchus lapathi*, was listed previously under the title BIODIVERSITY. However, MPM student Ms. Cindy Broberg has shown clearly that while the impact of the weevil on individual tress may be severe, in no case does it threaten any species with extinction, hence the impact on biodiversity will be slight.

- In her research Ms. Broberg conducted a survey in order to document: 1) the distribution and prevalence of *C. lepathi*, in B.C. within different bioeoclimatic subzones and *Salix* hosts; and 2) the between tree and within-tree dynamics of *C. lapathi*. The survey spanned 5 biogeoclimatic zones, 15 subzones, 45 locations, 135 sites, and 3360 trees, 675 of which were measured in detail. The widespread range of *C. lapthi* has at least doubled since 1963. The weevil was present in 38 locations and 14 subzones. The intensity of attack and the number of weevils were positively related to the prevalence of attacked trees. The prevalence of weevil-attacked trees was significantly different between biogeoclimatic subzones, with colder subzones tending to have fewer attacked trees. Using climate data available for subzones, Ms. Broberg constructed different regression models that could accurately predict the prevalence of weevil attacks. There was no evidence of host preference, but there were 12 new host records. In general, attacked trees were larger, had more dead wood and stems, more adventitious branches per stem, more total breaks per stem, and more naturally caused breaks per stem than their attack-free neighbours. Breaks

caused by *C. lapathi* tended to be slightly larger in diameter than naturally caused breaks, and to occur lower on the stem. The bases of large stems were preferentially attacked. Ms. Broberg has already begun her Ph.D. research focussing on the chemical ecology of host selection and mating, and expanding her scope to do a comparative study on *C. lapathi* and *Saperda calcarata*, the major cerambycid borer on trembling aspen, a species avoided by the weevil.

- Ms. Broberg presented her results at the annual meeting of the Entomological Society of Canada in Saskatoon, Saskatchewan in September 1999.

E. IMPACT ASSESSMENT OF THE WESTERN CONIFER SEED BUG (FRBC ref. #PA97510)

This project has been wholly funded by Forest Renewal B.C. since 1 April 1997, and is at the mid-year point of the third of four years. The project is a collaborative effort between me, Dr. Allison Kermode, an Associate Professor and seed physiologist in SFU's Department of Biological Sciences, Dr. Robb Bennett, Seed Orchard Pest Management Officer in the B.C. Forest Service, Saanichton, B.C. and more recently Dr. Ward Strong, Interior Cone and Seed Pest Biologist, B.C. Forest Service, Kalamalka Research Station, Vernon, B.C. A preliminary laboratory study on Douglas-fir seeds in my laboratory yielded refined methodology and impact data, which were applied to field studies using seed bugs caged on cones of first Douglas-fir and more recently lodgepole pine. Concurrently we used biochemical analyses for lipid and protein depletion developed in Dr. Kermode's laboratory and an antibody-based test for detection of *Leptogossus occidentalis* feeding, is being tested in lodgepole pine.

- Excellent progress was made in 1998-1999 in developing the antibody test. The following is a summary of the methodology used in this project spearheaded by Postdoctoral Fellow Dr. Cam Lait, who works in Dr. Kermode's laboratory.

  Excised salivary glands (10 pairs) from 4th instar nymphs of *L. occidentalis* were homogenized in 0.1 mL of isotonic saline consisting of 0.05 M Tris-HC1 pH 7.0. The

homogenate was centrifuged at 14 000 x g for 2 min to pellet debris and the supernatant, containing antigens from the salivary glands was kept.

Polyclonal antibodies were raised against SDS-denatured salivary antigens. Salivary gland proteins were suspended in 100 µL of isotonic saline. The antigen mixture was emulsified with an equal volume of Titer Max™ adjuvant and injected intramuscularly into 3-month old rabbits immediately after pre-immune serum samples were collected, as well as 28 days later. Serum samples were taken from rabbits after 56 days and tested, using Western blots, for the presence of polyclonal antibodies that recognized salivary gland proteins.

Any cross-reacting antibodies that recognized undamaged Douglas-fir seed proteins were removed from antisera using affinity absorption. Total Douglas-fir seeds proteins were extracted with buffer consisting of 62.5 mM Tris-HC1 pH 6.8, 2% SDS (w/v). To 10 mL of Affi-Gel 10 (BioRad Laboratories USA) 30 mg of total extract was added and mixed on a rocking platform for 4 h at 4°C. One milliliter of 0.1 M ethanolamine HC1 pH 8.0 was added to the gel and mixing was continued for 1 h. A 1.0 x 10 cm chromatography column was packed with the affinity gel and equilibrated with 5 volumes of phosphate buffered saline pH 7.5 (PBS). A 3.0 mL aliquot of rabbit antisera, raised against *L. occidentalis* salivary gland extract proteins, was loaded onto the column and the flow stopped. After 3 h of exposure, the column was rinsed with 5 column volumes PBS and the first 6.0 mL of eluted antibodies were kept. Column regeneration was performed using 5 column volumes of 0.01M sodium phosphate pH 12.5 to elute antibodies with affinity to seed proteins and a re-equilibration step using 5 column volumes of PBS.

Individual Douglas-fir seeds were homogenized in 250 µL of chilled buffer-A consisting of 0.05 M $NaPO_4$ pH 7.5 and 5 µM leupeptin (Sigma Co., St. Louis, MO, USA). The homogenate was centrifuged at 14 000 x g for 30 min and supernatant containing matrix proteins was transferred to a new microcentrifuge tube. An equal volume of buffer-B, consisting of 62.5 mM Tris-HC1 pH 6.8, 2% SDS (w/v) and 10% glycerol (v/v) was added to the matrix protein sample. The remaining pellet was further washed and centrifuged, as above, three times using 1 mL of buffer-A each time and discarding the supernatant. The pellet was re-suspended in 250 µL of buffer-B, boiled 5 min and cooled.

Following centrifugation at 14 000 x g for 15 min, the supernatant containing crystalloid proteins was transferred to a new microcentrifuge tube. Individual lodgepole pine seed proteins were extracted as above except 150 µL of buffers A and B were used in each step. Total seed protein extracts were generated by homogenizing seeds in 250 µL of buffer-B (150 µL of buffer-B for lodgepole pine) and centrifugation at 14 000 x g for 30 min to pellet debris. The supernatant was transferred to a new microcentrifuge tube and kept for further analysis. Protein quantity was determined (prior to the addition of 2-mercaptoethanol for reduced samples) using the Bio-Rad D_c Protein Assay with bovine serum albumin fraction V as a standard.

Extracted proteins were subjected to SDS Page under non-reducing or reducing conditions (2-mercaptoethanol added to samples) with 15% acrylamide resolving gels using the Bio-Rad Mini-Protean II apparatus. Proteins used for SDS PAGE were dissolved in sample buffer containing 60 mM Tris-HC1 (pH 6.8), 4% SDS, 20% glycerol, and 2-mercaptoethanol (for reducing conditions only). Proteins from salivary gland extracts and from fed-on seeds, previously categorized into various damage categories, were transferred from PAGE gels to nitrocellulose membranes according to the electroblotting (Western blot) method.

Proteins transferred to nitrocellulose membranes were blocked overnight in Tris-buffered saline (TBS) containing 5% (w/v) non-fat milk powder. Nitrocellulose membranes were then incubated at room temperature with affinity absorbed primary polyclonal antibody (1:5000) raised against denatured *L. occidentalis* salivary gland protein extracts. Secondary antibody conjugated to alkaline phosphate (1:10000) was used to detect positive antibody binding when 5-bromo-4-chloro-3-indolyl phosphate (BCIP) and nitro blue tetrazolium (NBT) were used to produce a colored product. All primary and secondary antibodies were diluted in Tris-buffered saline containing 1% (w/v) non-fat milt powder and 0.05 Tween 20 (TTBS).

Testing for potential cross-reactivity of polyclonal antibodies with undamaged seed proteins from Douglas-fir yielded a single cross-reacting protein band in undamaged control seeds on Western Blots that were incubated with polyclonal antibody. Affinity absorption was used to successfully remove the antibodies that cross-reacted with this seed

protein. Further testing of the affinity absorbed polyclonal antibody indicated no croo-reactivity with lodgepole pine proteins from undamaged seeds.

Preliminary results with the antibody-based bioassay are very promising. Using single-seed homogenates, the test accurately distinguished between empty seeds caused by *L. occidentalis* feeding and empty seeds that resulted from developmental abortion (or lack of pollination). Ph.D. students Ms. Sarah Bates is now evaluating the test for its ability to detect lodgepole pine seed that have been emptied by *L. occidentalis* feeding in the field. If successful, she will then apply the test to the 19,000 empty seed obtained in 1998 from exposing developing cones in different periods through the season to cone bugs of different developmental stages. Combined with information obtained by radiography on partially-depleted seeds, this enormous data set will allow Ms. Bates to predict the potential impact of *L. occidentalis* of any stage found on lodgepole pine at any time of the season. In addition, cones of five other species (western hemlock, western white pine, ponderosa pine, pacific silver fir and white spruce) were caged and exposed to *L. occidentalis* feeding for 2-3 weeks in late summer of 1999 in order to obtain damaged seed for testing. This will provide a very extensive evaluation of the new antibody-based detection test.

- The 1999 field season was a poor one for *Leptoglossus* research, because of low numbers of bugs throughout most of the summer. Nonetheless, Ms. Bates soldiered on in various aspects of her Ph.D. research on the impact of seed bugs on lodgepole pine seed production. This included evaluation in two orchards of six potential trapping methods [hanging malaise traps, window pane traps, cones coated with Tanglefoot, sticky cards (blue and yellow) and sticky pipe traps (unbaited and baited with host volatiles)], which could potentially be used to develop an early season monitoring system. Of the six traps tested at least two (sticky cards and sticky pipes) show potential for trapping *L. occidentalis*. She also conducted an experiment on the effect of feeding by adult *L. occidentalis* on conelet abortion. One adult female was placed on conelets alone, or cones with conelets for three weeks in early August. Unexposed cones and conelets served as a control. In the summer of 2000, conelet abortion and seed set in exposed conelets will be evaluated. Finally, Ms. Bates is continuing a low key effort on the chemical ecology of *L. occidentalis*, focussing on capture and analysis of male-produced volatiles in the fall, and

on development of a laboratory bioassay for evaluating conophthorin and other non-host volatiles as a potential seed bug feeding and oviposition deterrent.

- Because of Dr. Lait's success in developing the antibody-based test for detection of feeding in empty seeds by *L. occidentalis*, we were approached and separately funded by Dr. Dan Miller, U.S. Forest Service, Athens, Georgia, to do similar research on *L. corculus*, the main pest of seed production on southern pines. If the salivary enzymes of the two species prove to be identical, or nearly identical, we will proceed in 2000 with evaluating the antibody test for *L. corculus*.

- In March, 1999 Ms. Bates successfully defended her Master of Pest Management thesis on the impact of *L. occidentalis* on Douglas-fir seed production. One manuscript from this thesis has been submitted to the journal of Economic Entomology, and two others are in preparation for submission to refereed journals.

- Ms. Bates presented her results at the annual meeting of the Entomological Society of America in Las Vegas, Nevada in December 1998, winning an Honourable Mention in the student competition. In June, 1999, Dr. Lait and Ms. Bates gave well-received talks at the Joint Meeting of the B.C. Seed Orchard Staff Group and the Western Seed Orchard Managers Association in Vernon, B.C.

- We are grateful to assistance and support in this project provided by Messers. Chris Walsh and Gary Clarke of the Kalamalka Seed Orchard, B.C. Forest Service Vernon, B.C. Mr George Nicholson, Nursery Manager, Riverside Forest Products, Armstrong, B.C., Mr. Tim Lee, Manager, Vernon Seed Orchard, Vernon, B.C., Mr. Peter Richter and Ms. Hilary Graham, Pacific Regeneration Technologies, Armstrong, B.C., and Ms. Janet Lane, Grandview Nursery and Seed Orchard, Armstrong, B.C.

F. PESTS OF CONIFER NURSERIES

- Research Associate Dr. Aileen Wardle has continued to work in collaboration with two members of SFU's Chemistry Department Dr. Keith Slessor and Ph.D. student Scott Baird on the sex pheromone of the tarnished plant bug, *Lygus lineolaris*. Lygus bugs have

emerged as major pests of conifer nurseries, causing seedlings to be stunted and deformed, and rejected as culls. The pheromone work requires exceedingly exacting chemical analyses, and meticulously conducted bioassay experiments. Field trapping in the summer showed that female *L. shulli* and *L. lineolaris* are definitely attractive to males under field conditions, so emphasis shifted to trying to capture and identify volatiles emitted by females outdoors. Conventional Porapak Q trapping did not reveal any new compounds released by females. SPME (Solid Phase Micro Extraction) collections contain female-specific peaks, not yet been identified. For 1999-2000, work will concentrate on identifying these compounds, and on bioassaying esters emitted by females in varying ratios, blends, and doses.

III. EXTENSION

Extension is an integral part of the Chair activities. Because no formal extension service is offered by S.F.U. we function independently, primarily through the following avenues:

- this report, which is sent to each of the Chair's 20 industrial sponsors, as well as to NSERC and the Science Council of B.C.;

- conducting field research as much as possible with the full knowledge, and often collaboration, of the Canadian and British Columbia Forest Services, as well as, industrial licensees responsible for management of forested and milling sites where the research is conducted (see acknowledgements in text to 28 industrial, 12 government, and 3 academic personnel);

- very frequent contact with Phero Tech Inc. (at least weekly) and Bugbusters Pest Management Inc. (at least monthly), the two principal industrial sponsors who will develop and market any new products and services arising from the Chair research;

- publishing results as rapidly as possible in the scientific press and if extension publications are available, publishing in them as well;

- seeking media coverage if results or activities are newsworthy, e.g. in CBC Radio, Prince Rupert in 1998, Simon Fraser News in 1999, and ABCPF FORUM in 1999;

- participating in relevant workshops and meetings likely to be attended by our clients, e.g. Forest Health Committee of B.C. field meetings, Phero Tech's fall seminars, and the Western Forest Insect Work Conference.

IV. PUBLICATIONS AND PATENTS (1 OCTOBER 1996 TO 30 SEPTEMBER 1999)

The publications listed in this section pertain only to forestry. I am wrapping up several agricultural projects, but have not listed an additional 17 publications arising from them.

A. PAPERS IN REFEREED JOURNALS

1. Bowers, W.W., J.H. Borden and A.G. Raske. 1996. Bionomics of the four-eyed spruce bark beetle, *Polygraphus rufipennis* (Kirby) (Col., Scolytidae) in Newfoundland. I. Emergence and flight patterns. J. Appl. Entomol. 120: 449-461.

2. Bowers, W.W., J.H. Borden and A.G. Raske. 1996. Bionomics of the four-eyed spruce bark beetle, *Polygraphus rufipennis* (Kirby) (Col., Scolytidae) in Newfoundland. II. Host colonization sequence. J. Appl. Entomol. 120: 449-461.

3. Wilson, I.M., J.H. Borden, R. Gries and G. Gries. 1996. Green leaf volatiles as antiaggregants for the mountain pine beetle, *Dendroctonus ponderosae* Hopkins (Coleoptera: Scolytidae). J. Chem. Ecol. 22: 1861-1875.

4. Miller, D.R., J.H. Borden and K.N. Slessor. 1996. Enantiospecific pheromone production and response profiles for populations of the pine engraver, *Ips pini* (Say) (Coleoptera: Scolytidae) in British Columbia. J. Chem. Ecol. 22: 2157-2172.

5. Blatt, S.E. and J.H. Borden. 1996. Distribution and impact of *Leptoglossus occidentalis* Heidemann (Hemiptera: Coreidae) in British Columbia seed orchards. Can. Entomol. 128: 1065-1076.

6. Tomlin, E.S. and J.H. Borden. 1997. Thin bark and high density of outer resin ducts: interrelated resistance traits in Sitka spruce against the white pine weevil. J. Econ. Entomol. 90: 235-239.

7. Macias-Samano, J.E., J.H. Borden, H.D. Pierce, Jr., R. Gries and G. Gries. 1997. Aggregation pheromone of *Pityokteines elegans* (Swaine) (Coleoptera: Scolytidae). J. Chem. Ecol. 23: 1333-1347.

8. Tomlin, E.S. and J.H. Borden. 1997. A multicomponent index for evaluating resistance by Sitka spruce to the white pine weevil. J. Econ. Entomol. 90: 704-714.

9. Partridge, M.J. and J.H. Borden. 1997. Evaluation of neem seed extract for control of the spruce aphid, *Elatobium abietinum* Walker (Homoptera: Aphididae). Can. Entomol 129: 899-906.

10. Tomlin, E.S. and J.H. Borden. 1997. Relationship between volatile foliar terpenes and resistance of Sitka spruce to the white pine weevil. For. Sci. 43: 501-508.

11. Blatt, S.E. and J.A. Janmaat. 1997. Use of Poisson regression for modelling host selection behaviour of the western conifer seed bug, *Leptoglossus occidentalis* Heidemann (Hemiptera: Coreidae). Proc. Entomol. Soc. Ont. 128: 65-83.

12. Poland, T.M. and J.H. Borden. 1997. Responses of a bark beetle predator, *Thanasimus undatulus* Say (Coleoptera: Cleridae), to pheromones of the spruce beetle and two sympatric bark beetle species (Coleoptera: Scolytidae). J. Entomol. Soc. B.C. 94: 35-41.

13. Borden, J.H., L.J. Chong, A. Savoie and I.M. Wilson. 1997. Responses to green leaf volatiles in two biogeoclimatic zones by the striped ambrosia beetle, *Trypodendron lineatum* (Olivier) (Coleoptera: Scolytidae). J. Chem. Ecol. 23:2479-2491.

14. Savoie, A., J.H. Borden, H.D. Pierce, Jr., R. Gries and G. Gries. 1998. Aggregation pheromone of *Pityogenes knechteli* Swaine (Coleoptera: Scolytidae) and semiochemical-based interactions with three other bark beetles. J. Chem. Ecol. 24: 321-337.

15. Tomlin, E.S., R.I. Alfaro, J.H. Borden and F. He. 1998. Histological response of resistant and susceptible white spruce to simulated white pine weevil damage. Tree Physiology 18: 21-28.

16. Poland, T.M. and J.H. Borden. 1998. Disruption of secondary attraction of the spruce beetle, *Dendroctonus rufipennis* Kirby, by pheromones of two sympatric secondary species (Coleoptera: Scolytidae). J. Chem. Ecol. 24: 1049-1075.

17. Macias-Samano, J.E., J.H. Borden, R. Gries, H.D. Pierce, Jr., G. Gries and G.G.S. King. 1998. Primary attraction of the fir engraver, *Scolytus ventralis* LeConte (Coleoptera: Scolytidae). J. Chem. Ecol. 24: 1049-1075.

18. Blatt, S.E., J.H. Borden, H.D. Pierce, Jr., R. Gries and G. Gries. 1998. Alarm pheromone system of the western conifer seed bug, *Leptoglossus occidentalis*. J. Chem. Ecol. 24: 1013-1031.

19. Borden, J.H., I.M. Wilson, R. Gries, L.J. Chong, H.D. Pierce, Jr. and G. Gries. 1998. Volatiles from the bark of trembling aspen, *Populus tremuloides* Michx. (Salicaeae) disrupt secondary attraction by the mountain pine beetle, *Dendroctonus ponderosae* Hopkins (Coleoptera: Scolytidae). Chemoecology 8: 69-75.

20. Poland, T.M. and J.H. Borden. 1998. Semiochemical–induced competition between the spruce beetle, *Dendroctonus rufipennis*, and two secondary species, *Ips tridens* and *Dryocoetes affaber* (Coleoptera: Scolytidae). J. Econ. Entomol. 91: 1142-1149.

21. Poland, T.M. and J.H. Borden. 1998. Competitive exclusion of the spruce beetle, *Dendroctonus rufipennis*, induced by pheromones of *Ips tridens and Dryocoetes affaber* (Coleoptera: Scolytidae). J. Econ. Entomol. 91: 1150-1161.

22. Camacho, A.D., H.D. Pierce, Jr. and J.H. Borden. 1998. Host compounds as kairomones for the western balsam bark beetle, *Dryocoetes confusus* (Col., Scolytidae). J. Appl. Entomol. 122: 287-293.

23. Blatt, S.E. and J.H. Borden. 1998. Interactions between the Douglas-fir seed chalcid, *Megastigmus spermotrophus* Wachtl. and the western conifer seed bug, *Leptoglossus occidentalis* Heidemann (Hemiptera: Coreidae). Can. Entomol. 130: 775-782.

24. Deglow, E.K. and J.H. Borden. 1998. Green leaf volatiles disrupt and enhance response by the ambrosia beetle, *Gnathotrichus retusus* (LeConte) (Coleoptera: Scolytidae) to pheromone-baited traps. J. Entomol. Soc. B.C. 95: 9-15.

25. Poland, T.M., J.H. Borden, A.J. Stock and L.J. Chong. 1998. Green leaf volatiles disrupt responses by the spruce beetle, *Dendroctonus rufipennis*, and the western pine beetle, *Dendroctonus brevicomis* (Coleoptera: Scolytidae) to attractant-baited traps. J. Entomol. Soc. B.C. 95: 17-24.

26. Deglow, E.K. and J.H. Borden. 1998. Green leaf volatiles disrupt and enhance response to aggregation pheromone by the ambrosia beetle, *Gnathotrichus sulcatus* (LeConte) (Coleoptera: Scolytidae). Can. J. For. Res. 28:1697-1705.

27. Macías-Sámano, J. E., J.H. Borden, R. Gries, H.D. Pierce, Jr. and G. Gries. 1998. Lack of evidence for pheromone-mediated secondary attraction in the fir engraver, *Scolytus ventralis* (Coleoptera: Scolytidae). J. Entomol. Soc. B.C. 95: 117-125.

28. Duthie-Holt, M.A. and J.H. Borden. 1999. Translocation and efficacy of a neem-based insecticide in lodgepole pine using *Ips pini* (Say) as an indicator species. J. Econ.Entomol. 92: 180-186.

29. Huber, D.P.W., R. Gries, J.H. Borden and H.D. Pierce, Jr. 1998. Two pheromones of coniferophagous bark beetles found in the bark of non-host angiosperms. J. Chem. Ecol. 25: 805-816.

30. Blatt, S.E. and J.H. Borden 1999. Physical characteristics as potential host selection cues for *Leptoglossus occidentialis* (Hemiptera: Coreidae). Environ. Entomol. 28: 246-254.

31. Setter, R.R. and J.H. Borden. 1999. Bioactivity and efficacy of MCOL and seudenol as potential bait components for the spruce beetle. *Dendroctonus rufipennis* Kirby (Coleoptera: Scolytidae). Can. Entomol. 131: 251-257.

32. Duthie-Holt, M.A. and J.H. Borden. 1999. Treatment of lodgepole pine bark with neem demonstrates lack of repellency or feeding deterrency to the mountain pine beetle, *Dendroctonus ponderosae* Hopkins (Coleoptera Scolytidae). J. Entomol. Soc. B.C. (in press).

33. Poirier, L.M. and J.H. Borden. 1999. The influence of larval diet on the repellent and feeding deterrent activity of larval oral exudate in spruce budworms. Can. Entomol. (in press).

34. Greenwood, M.E. and J.H. Borden. 1999. Co-baiting for spruce beetles, *Dendroctonus rufipennis* (Kirby), and western balsam bark beetles, *Dryocoetes confusus* Swaine (Coleoptera: Scolytidae). Can. J. For. Res. (in press).

35. Bates, S.L. C.G. Lait, J.H. Borden, A.R. Kermode, A. Savoie, S.E. Blatt and R.G. Bennett. 1999. Impact of feeding by *Leptoglossus occidentalis* (Hemiptera: Coreidae) on the major storage reserves of mature Douglas-fir (Pinaceae) seed. Can. Entomol. (in press).

36. Macías-Sámano, J. E., J.H. Borden. 1999. Interactions between *Scolytus ventralis* and *Pityokteines elegans* (Coleoptera: Scolytidea). Environ. Entomol. (in press).

37. Miller, D.R., H.D. Pierce Jr., P. de Groot, N. Jeans-Williams, R. Bennett and J.H. Borden. 1999. Sex pheromone of the ponderosa pine cone beetle, *Conopthorus ponderosae* (Coleoptera: Scolytidea). Can. Entomol. (in press).

B. CHAPTERS IN BOOKS

1. J.H. Borden. 1997. Disruption of semiochemical-mediated aggregation in bark beetles (Coleoptera: Scolytidae). pp. 421-438. In: Pheromone research: new directions. R.T. Cardé and A.K. Minks (eds.). Chapman and Hall, N.Y.

C. NON-REFEREED PUBLICATIONS

1. Savoie, A., J.H. Borden, S.E. Blatt, A.R. Kermode and R.G. Bennett. 1996. Damage caused by the western conifer seed bug, *Leptoglossus occidentalis* (Hemiptera: Coreidae) to Douglas-fir seeds. Seed and Seedling Extension Topics, B.C. Min. For. 9(2): 8-10.

2. Alfaro, R.I., E. Tomlin, J.H. Borden and F. He. 1996. Screening spruce for genetic resistance to white pine weevil. pp. 42-43. In: Tree Improvement Council of British Columbia, Progress Report to 1996. M. Crown and D. Reid (compilers). B.C. Min. For., Victoria, B.C.

3. Bates, S.L., J.H. Borden, A.R. Kermode, C.G. Lait and R.G. Bennett, 1997. New impact of the western conifer seed bug, *Leptoglossus occidentalis*, on developing Douglas-fir seeds. Seed and Seedling Extension Topics. B.C. Min. For. 10(1 & 2): 24-26.

4. Harder, L and L.E. Maclauchlan. 1997. Containment and concentration of western balsam bark beetle in patch- and partial-cut of silvicultural systems. pp. 32-40. In: Sicamous Creek Silvicultral System Project: Workshop Proceedings, April 24-25,

1996, Kamloops, B.C. C. Hollstedt and A. Vyse. (eds.). B.C. Ministry of Forests, Victoria. B.C.

5. Borden, J.H. 1998. Is forest health healthy? Assoc. of B.C. Prof. Foresters FORUM, Nov-Dec: 4-5.

6. Borden, J.H. 1998. New concepts in host and non-host volatiles. pp 17-18. In: Proc. 49th Ann. West For. Ins. Wk. Conf., Jackson, Wyoming, Mar. 2-5, 1998.

7. Alfaro, R.I., E.S. Tomlin, J.H. Borden and K. Lewis. 1999. Interaction of the white pine weevil (*Pissodes strobi* Peck) and its hosts: arguments for co-evolution. pp. 31-39. In: Physiology and genetics of tree-phtophage interactions. F. Lieutier, W.J. Mattson and M.R. Wagner (eds.) INRA, Paris.

8. Bates, S.L., J.H. Borden, A.R. Kemode, C.G. Lait, R.G. Bennett and D. Summers. 1999. Germination and seedling vigour of Douglas-fir grown from seeds damaged by the western conifer seed bug, *Leptoglossus occidentalis*. Seed and Seedling Extension Topics, B.C. Min. For. (in press).

9. McIntosh, R.L., J.D. Allison, J.H. Borden, R. Gries, and H.D. Pierce, Jr. 1999. Control of wood-borers using semiochemicals: an ecological approach. In: Integrating environmental values into small-scale forestry. Proc. IUFRO Conf., Univ. B.C., 16-22 Aug., 1998. (in press).

D. PATENT

1. Borden, J.H., L.J. Chong, G. Gries, R. Gries, D.P.W. Huber, H.D. Pierce, Jr. and I.M. Wilson. 1997. Non-host volatiles as disruptants for bark beetles. U.S. Patent Application No. 88/986, 823, submitted December 1997.

E. LETTER TO THE EDITOR

1. The Vancouver Sun, 19 August 1997.

V. PROFESSIONAL AND EXTENSION CONTRIBUTIONS (J.H. BORDEN, 1996-9)

1. Member, Forest Health Committee of B.C. Attended meetings in: Nelson, 13-14 May, 1997; Victoria, 11 December, 1998; Smithers, 26-27 May, 1998; and Williams Lake 23-25 June, 1999. At the December, 1998 meeting tabled report to the Chair, Chief Forester Larry Pederson entitled "Analysis of Forest Health Capability in British Columbia, 1990-1997" arising from an *ad hoc* subcommittee that I chaired. At the May, 1998 meeting pushed through two motions, one urging the government to restore forest health funding to the 1997 level, and the other requesting that the government formally take over forest insect and disease surveys and to establish a Forest Health Monitoring Unit within the Ministry of Forests. Made presentation on mountain pine beetle on 24 June, 1999 field trip.

2. Member, Western Forest Insect Work Conference, Founders' Award Committee (resigned May, 1997).

3. Member, Program Committee, Annual Meeting of the International Society of Chemical Ecology, held from 13-16 July, 1997 in Vancouver, B.C. Chair of symposium on bark beetle pheromones.

4. Member, Committee of Forest Research Agencies (COFRA) of B.C. On behalf of COFRA submitted brief to Ms. Jana Kumi, Assistant Deputy Minster, Operations, B.C. Ministry of Forests, entitled "A Lease-based Tenure System for Crown Forests in British Columbia", 21 October 1998.

5. Member, Advisory Committee, Agriculture and Agri-Food Canada Research Station, Summerland, B.C. Attended meetings in Summerland on 26 March and 12 September, 1997, and 14 October, 1998.

6. Chair, Advisory Committee, Centre for Forest Biology, University of Victoria. Attended meetings in Victoria on 26 January and 30 September, 1998.

7. Member, Program Committee, Second International Symposium on Insect Pheromones, held in Wageningen, the Netherlands, 30 March - 3 April, 1998. Co-chair of session on applied use of pheromones.

8. Member, NSERC Site Visit Committee to the University of Guelph, 22-23 January, 1997.

9. Member, Advisory Committee to Department of Chemical Ecology, International Centre of Insect Physiology and Ecology, Nairobi, Kenya, appointed September 1997.

10. Director, Chemical Ecology Research Group, SFU.

11. Faculty in Charge of Insectary, SFU.

12. Senior Supervisor (current) of three Postdoctoral Research Associates, two Research technicians, four Ph.D. students, and six M.P.M. students.

13. Served on Supervisory Committee of one undergraduate Honours student, two Ph.D. students, five M.P.M. students and one M.Sc. student who graduated since 1 October, 1996.

14. Currently on Supervisory Committee of seven Ph.D. students, one M.Sc. student and six M.P.M. students.

15. Sponsoring Forester for six Foresters in Training, Association of B.C. Professional Foresters, one registered in 1997.

16. Public Examiner for two M.P.M. theses and one M. Sc. thesis at S.F.U. since 1 October, 1996; External Examiner for Ph.D. thesis, Faculty of Forestry, University of Toronto, 1997.

17. Tenure and promotion reviewer for: Faculty of Forestry, Oregon State University, 1996; University of Ghana, 1997; Hebrew University of Jeruselum, 1998; University of California, Riverside, 1998 and 1999.

18. Reviewer of three research grant proposals, two from NSERC and the other from the U.S. National Science Foundation since 1 October, 1996.

19. From 1 October, 1996-30 September, 1999 reviewed 30 manuscripts for the following journals (number of manuscripts in parentheses): Entomologia Experimentalis et Applicata (5), Canadian Journal of Forest Research (3), Environmental Entomology(1), Naturwissenschaften(1), Journal of Chemical Ecology(7), the Canadian Entomologist (1), Journal of the Entomological Society of B.C. (2); Journal of Economic Entomology (3); Ecological Applications (1); Annals of the Entomological Society of America(1), Canadian Journal of Zoology (1), Chemoecology (1), Agricultural and Forest Entomology (1), and the Journal of Insect Physiology (1).

20. Member, University Tenure Committee, SFU, 1995-7.

21. Member, M.P.M. Admissions Committee, 1986-present.

22. Presented invitational lectures at: 1) University of Guelph, 1997; 2) University of Toronto, 1997; 3) 25th Anniversary Meeting of SFU's Centre for Pest Management, 1997; 4) Annual Meeting of the International Society of Chemical Ecology, Vancouver, B.C., 1997; 5) Austrian Agricultural University, Vienna, March 1998; 6) Second International Symposium on Insect Pheromones, Wageningen the Netherlands 1998(2); 7) Royal Danish Veterinary and Agricultural University, Copenhagen, November 1998; 8) Seventh Annual Alberta – B.C. Intermountain Forest Health Workshop, Radium, B.C. 1999; 9) Phero Tech Technical Seminar, Williams Lake, B.C., 1999; and 10) Joint Meeting of B.C. Seed Orchard Staff Group and Western Seed Orchard Manager Association, Vernon, B.C., 1999 (2).

23. Senior or co-author of 25 submitted papers at various scientific meetings since 1 October 1996. Invited discussant at Western Forest Insect Work Conference, (WFIWC), Prince George, B.C., April 1997, and Chaired workshop on semiochemicals of forest insects at WFIWC meeting in Jackson Hole, Wyoming, March 1998.

24. Consultant (unpaid) to Slocan Forest Products, Bugbusters Pest Management Inc., and the B.C. Forest Service on forest decline following spruce budworm defoliation, Fort Nelson, B.C. 29-30 September, 1997.

25. Consultant (unpaid) on mountain pine beetle management, joint workshop, B.C. Ministry of Forests and Alberta Department of Environmental Protection, McBride, B.C., 22 January, 1999.

26. Member, Editorial Board, Journal of Chemical Ecology.

27. Research program, opinion or activities featured in: the Vancouver Sun, April 1997; Burnaby Now, August 1997; Simon Fraser News, October, 1997 (twice); The Vancouver Sun, December, 1997; New Scientist, January 1998; Natur & Vetenskap (Sweden), August, 1998; Canadian Geographic, August, 1998; Arrow Lakes News, October, 1998; Simon Fraser News, December 1998; 20/20 Vision, Science Council of B.C., November, 1998; Simon Fraser News, March, 1999; Assoc. of B.C. Professional Foresters FORUM, May, 1999; Simon Fraser News, July, 1999; Entomological Society of America Newsletter, September, 1999; Association of B.C. Professional Foresters FORUM, September/October, 1999.

28. Guest Instructor: Forest Entomology (1h), UBC, 1997; Insect Biology (1h), S.F.U., 1998.

29. Letters written from 1 October, 1996 to 30 September, 1997: 1) to Canadian Pest Management Regulatory Agency critiquing Draft Guidelines for the Research and Registration of Pest Control Products Containing Pheromones and Other Semiochemicals; 2) to Forest Renewal B.C., suggesting greater participation in

NSERC's CRD program, 3) to Forest Renewal, B.C. critiquing policy on protection of intellectual property; and 4) to the Vancouver Sun commenting on the need for rapid response to bark beetle infestations in a response to a reported Forest Practices Board audit of MOF Lakes District. Letters from 1 October, 1997 to 30 September, 1998: 1) to the Honourable Paul Martin, Minister of Finance, indicating the benefits in employment and yield of intellectual property gained from public investment in research; and 2) to Revenue Canada in support of continued tax deductions for Phero Tech Inc. for donations in support of my Research Chair. Letters from 1 October, 1998 to 30 September, 1999; 1) to Larry Pederson Chief Forester of B.C., pleading for the Heritage Camp at the Cowichan Research Station to remain open; and 2) to the Pest Management Regulatory Agency, Health Canada, pointing out deficiencies in efficacy data for the first two provisional registrations of pheromones as pesticides in Canada.

30. Taught: BISC 602-5, Forest Pest Management in Summer Semesters, 1997 and 1998; and BISC 847-3, Pest Management in Practice in Fall Semesters, 1996 and 1997.

31. Maintained membership in eight scientific societies, and professional registrations in the Association of B.C. Professional Foresters, the Association of Professional Biologists of B.C., and the American Registry of Professional Entomologists.

32. Received Hewlett Packard Canada Forum Award (presented in Montreal, October, 1997).

33. Organizer and principal instructor in week-long intensive course entitled "Applied Entomology and Semiochemicals," Swedish University of Agricultural Sciences, Uppsala, November, 1999.

34. Best Paper Award in 1999 in FORUM, journal of the B.C. Association of Professional Foresters.

35. Elected Fellow of the Royal Society of Canada, May 1999.

VI. GRADUATES

From 1 October 1996 to 30 September 1999, three Ph.D. candidates, one M. Sc. candidate and eight Master of Pest Management (M.P.M.) students (as listed below) finished their programs of study and research and defended their theses in forest entomology under my supervision. Not listed are one Ph.D. candidate, and two M.P.M. students in agriculture, and one M.P.M. student in forensic entomology who also completed their degrees. These were the last of my non-forestry students.

M.A. DUTHIE

Degrees: B.Sc., U.Vic., M.P.M., SFU, April 1997

Thesis Title: Evaluation of a neem-based insecticide for control of the mountain pine beetle.

Present Position: Forest Entomologist, Bugbusters Pest Management Inc., Prince George, B.C.

T.K. KIMOTO

Degrees: B.Sc., SFU; M.P.M., SFU, April 1997

Thesis Title: Past infestations of the white pine weevil, *Pissodes strobi* (Coleoptera: Curculionidae) in naturally regenerated stands of the McGregor Model Forest, Prince George, British Columbia.

Present position: Pest Management Specialist, Phero Tech Inc., Delta, B.C.

T.M. POLAND

Degrees: B.Sc., M.P.M., SFU; Ph.D., SFU, May 1997

Thesis Title: Competitive interactions between the spruce beetle, *Dendroctonus rufipennis* Kirby, and two secondary species, *Ips tridens* Mannerheim, and *Dryocoetes affaber* Mannerheim (Coleoptera: Scolytidae).

Present Position: Research Entomologist, USDA Forest Service, East Lansing, Michigan

S.E. BLATT

Degrees: B. Agric., N.S. Agric. Coll.; Ph.D., SFU, June 1997

Thesis Title: Host selection, impact and chemical ecology of the western conifer seed bug, *Leptoglossus occidentalis* Heidemann (Hemiptera: Coreidae).

Present Position: Contract Researcher and Instructor, Queen's University, Kingston, Ontario (while husband studies for Ph.D.)

E.K. DEGLOW

Degrees: B.Sc., SFU; M.P.M., SFU, June 1997

Thesis Title: Effects of green leaf volatiles on the response to aggregation pheromones by two species of ambrosia beetles.

Present Position: Pest Management Specialist, Phero Tech Inc., Delta, B.C.

R.R. SETTER

Degrees: B.Sc., SFU; M.P.M., SFU, August 1997

Thesis Title: Potential adjuvents to attractive baits for the spruce beetle, *Dendroctonus rufipennis* Kirby (Coleoptera: Scolytidae).

Present Position: Head, Entomology Department, Bugbusters Pest Management Inc., Prince George, B.C.

J.E. MACÍAS-SÁMANO

Degrees: B.Sc., National Polytechnic Institute, Mexico; M.P.M. S.F.U.; Ph.D., S.F.U., November 1997.

Thesis Title: Chemical ecology of *Scolytus Ventralis* LeConte and *Pityokteines elegans* (Swaine), two bark beetles of *Abies grandis* (Dougl.) Lindl.

Present Position: Research Scientist (Forest Entomology), ECOSUR, Chiapas Mexico.

L. HARDER

Degrees: B.Sc., SFU; M.P.M., SFU, December 1998

Thesis Title: Impact of the western balsam bark beetle, *Dryocoetes confusus*, at the Sicamous Creek Research Site, and potential for semiochemical-based management in alternative silviculture systems.

Present Position: Chemist in Japan

M.E. GREENWOOD

Degrees: B.Sc., SFU; M.P.M., SFU, December 1998

Thesis Title: Co-baiting for spruce beetles, *Dendroctonus rufipennis* (Kirby), and western balsam bark beetles, *Dryocoetes confusus* Swaine (Cloeoptera: Scolytidae).

Present Position: Enrolled in intensive 9-month computing program, in preparation for employment resource planning career.

S.L. BATES

Degrees: B.Sc., Guelph; M.P.M., SFU, March 1999

Thesis Title: Impact of feeding by the western conifer seed bug, *Leptoglossus occidentalis* Heidemann (Hemiptera: Coreidae), on seed yield, seed storage reserves and seedling vigour in Douglas-fir.

Present Position: Ph.D. student, Department of Biological Sciences, SFU

D.S. PURESWARAN

Degrees: B.Sc., Madras Christian College, India; M. Sc., SFU, July 1999

Thesis Title: Dynamics of pheromone production and communication in the mountain pine beetle, *Dendroctonus ponderosae* Hopkins, and the pine engraver, *Ips pini* (Say) (Coleoptera: Scolytidae).

Present Position: Ph.D. student, Department of Biological Sciences, SFU

N.L. JEANS WILLIAMS

Degrees: B.Sc., SFU; M.P.M., SFU, August 1999

Thesis Title: Evaluation of pheromone baits for the western balsam bark beetle, *Dryocoetes confusus* Swaine (Coleoptera: Scolytidae), and partial elucidation of the pheromone for *Dryocoetes autographus* Ratzeburg.

Present Position: Pest management consultant for own company, For-Health Management, Salmon Arm, B.C.

VII. RESEARCH PERSONNEL

Unlike the five Annual Reports for Phase I of the Chair, no personnel involved in agricultural research are listed in this report. Moreover, despite a very active continuing collaboration with Dr. Gerhard Gries, the junior chair appointee, no personnel pursuing independent research in his laboratory are listed.

A. POSTDOCTORAL PERSONNEL

H.D. PIERCE, Jr., University Research Associate

Degrees: B.Sc., Ph.D., Illinois.

Subject Area: Volatile capture and extraction, analytical and synthetic organic chemistry, advising graduate students.

A.R. WARDLE, Research Associate

Degrees: B.Sc., UBC; M.P.M., Ph.D., SFU.

Subject Area: Chemical ecology and management of lygus bugs.

E.S. TOMLIN, Postdoctoral Fellow (1996-8)

Degrees: B.Sc., Western Ontario; M.Sc., Guelph; Ph.D., SFU.

Awards: NSERC Postdoctoral Fellowship.

Subject Area: Resistance mechanisms in spruce against the white pine weevil.

Present Position: (as of 1 August 1998): Assistant Professor (temporary) Department of Biology, University of North Carolina, Greensboro.

R.L. MCINTOSH, Postdoctoral Fellow

Degrees: B.S.F., Univ. of New Brunswick; M.Sc., Ph.D., UBC.

Subject Area: Chemical ecology and management of woodboring beetles.

C.G. LAIT, Postdoctoral Fellow

Degrees: B.Sc., Univ. Victoria.; Ph.D., Alberta.

Subject Area: Biochemistry of impact of seed bug feeding on conifer seeds.

B. RESEARCH TECHNICIANS

L.J. CHONG

Degree: B.Sc., SFU.

Subject Area: Support services and coordination for research on chemical ecology and management of forest insects.

R. GRIES

Degree: M. Agr., Göttingen, Germany.

Subject Area: GC-EAD analysis, bioassays, maintenance of GC-EAD laboratory and coordination of laboratory services.

A. SAVOIE (1996-7)

Degrees: B.Sc., McGill (MacDonald Campus), M.P.M., SFU.

Subject Area: Impact of the western conifer seed bug.

Present Position: Pest Management Consultant, Whitehorse, Yukon.

P.P. MOREWOOD

Degrees: Diplom, Eberhard Karls Univ., Germany, M.P.M., SFU.

Subject Area: Chemical ecology of bark beetles, impact of seed bugs

P.J KATINIC

Degrees: B.Sc., SFU

Subject Area: Chemical ecology of woodboring beetles

C. PH.D. STUDENTS IN COURSE

D.P.W. HUBER

Degree: B.Sc., Univ. of Calgary.

Awards: NSERC Scholarship with supplement from the Canadian Forest Service.

Subject Area: Bioactivity and application of non-host volatiles against bark beetles.

S. KÜHNHOLZ

Degrees: Dip. Univ. Wurzburg

Awards: S.F.U. Graduate Fellowship

Subject Area: Chemical ecology and interaction between four species of *Trypodendron* native to British Columbia.

S.L. BATES

Degrees: B.Sc., Univ. Guelph; MPM, SFU

Award: NSERC Graduate Scholarship, Entomological Society of Canada Graduate Scholarship.

Subject Area: Impact assessment of the western conifer seed bug on lodgepole pine.

D.S. PURESWARAN

Degree: B. Sc., Madras Christian Coll.; M.Sc., SFU

Awards: SFU Graduate Fellowship.

Subject Area: Role of tree and beetle volatiles in maintaining host specificity and reproductive isolation in coniferophagous bark beetles.

D. MASTER OF PEST MANAGEMENT STUDENTS IN COURSE

C.L. BROBERG

Degree: B.Sc., Okanagan Univ. Coll. in coop. with UBC

Award: SFU Graduate Fellowship, Entomological Society of Canada Graduate Scholarship, NSERC Graduate Scholarship with supplement from Canadian Forest Service.

Subject Area: Impact and chemical ecology of the poplar and willow borer.

J. S. BURLEIGH

Degree: B.Sc. S.F.U. (including one year in Forestry at University of Alberta as exchange student).

Award: GREAT Award, Science Council of B.C.

Subject Area: Woodborers and forest decline in the Laird-LaBiche area in northern B.C.

J. D. ALLISON

Degree: B.Sc., Guelph

Award: GREAT Award, Science Council of B.C.

Subject Area: Role of bark beetle pheromones in host selection by woodborers in the genus *Monochamus*.

J.E. GOUDIE

Degree: B.Sc., Memorial

Subject Area: Effect of thinning and pruning stress on the susceptibility of lodgepole pine to secondary pests, and chemical ecology of *Pissodes schwarzi*.

J.A. TANAKA

Degree: B.Sc., SFU

Subject Area: Chemical ecology of the white pine weevil

E. RESEARCH ASSISTANTS

1997

E. ANTONIJEVIC, B.Sc., SFU (left science to start a landscaping business).
D. ELM, Office Worker, SFU.
N.L. JEANS, B.Sc., Biological Sciences, SFU.
E.K. MORIN, Hastings Jr. Secondary School, Port Coquitlam.
K.A. HARDACKER, Biological Science major, SFU.
M.L. NORTON, Biological Science major, SFU.
C.H. SILVA, Environmental Science major, SFU.
J.D. ALLISON, Biological Science major, Univ. Guelph.
N.A. JENSEN, Environmental Science major, SFU.
M. JONES, Cariboo Secondary School, Burnaby.
G.J.A. YAKEL, Biological Science major, SFU.
S.L. BATES, B.Sc., Biological Sciences, Univ. Guelph.
C.L. BROBERG, B.Sc., Botany, Okanagan Univ. Coll.

1998

M. STASTNY, Biological Sciences Major, SFU
M. GAJECKI, Biological Sciences Major SFU
K. MACDONALD, Qualifying Graduate Student, SFU
J.A. TANAKA, Biological Sciences Major, SFU
J. CHUO, Biological Sciences Major, SFU
T. KOPYTKO, Biological Sciences Major, SFU

E.E. CZYZEWKSA, Research Associate (part-time), Engineering Sciences, SFU (hired to do contract syntheses of bark beetle pheromones).

1999

N.L. JEANS-WILLIAMS, B.Sc., M.P.M., SFU
M.E. GREENWOOD, B.Sc., M.P.M., SFU
J.A. TANAKA, B.Sc., SFU
M.C. SIDNEY, B.Sc., SFU
J. FUEST, Biological Sciences Major, SFU
M. STASTNY, Biological Sciences Major, SFU

VIII. PHYSICAL RESOURCES

- Chair activities are principally housed in a 247 m^2 laboratory at SFU comprising a general purpose area with bench space and desks for one Technician, 2 Postdoctoral Fellows and 6 Graduate Students. Shared with an apiculturist, who has 9 personnel of his own, this laboratory fills up between April and October with 10-14 summer student Research Assistants. Three of Dr. Slessor's students also use the laboratory. It is truly a "bee hive" of activity. In addition, the Chair maintains a 35 m^2 rearing room for bark beetles, woodboring beetles and terminal weevils in SFU's Insectary Annex, occupies (at $1.00 per day) two additional 6 m^2 insect rearing rooms for lygus and seed bugs in the Annex, maintains a 9 m^2 greenhouse for raising host plants for lygus bugs, and a 13 m^2 olfactometer room, which also houses a laminar air flow hood for sterile procedures, and has access to a wind tunnel for behavioural research in a separate laboratory maintained by Dr. Gries. In an unexpected windfall, the Chair acquired an unused and deteriorating 27.5 m^2 house trailer for $1.00 from SFU's Geography Department. This trailer has been moved to a permanent location and has been adapted by Dr. McIntosh into a bulk-rearing facility for wood-boring beetles.

- The Chair depends on a laboratory in SFU's Department of Chemistry. This is a 100 m^2 laboratory in which Dr. Pierce performs volatile capture, extraction and analysis, and in which Dr. Grigori Khaskin does chemical syntheses under the direction of Dr. Gries. Dr. Gries and I have received notice that in June 2000, the Department of Chemistry intends to evict us from this laboratory. At the time of writing, suitable alternative space had not yet been found.

- In 1999, the world-class laboratory in which Ms. Regine Gries performs magic with coupled gas chromatographic-electroantennographic detection analysis (GC-EAD) was successfully moved to a new 33 m^2 location in the Department of Biological Sciences. Housed in an adjacent laboratory is a new GC-MS machine purchased in part with Chair funding.

- My laboratory maintains three pick up trucks (in addition to three leased vehicles under FRBC grants), two outdoor walk-in cold rooms for maintenance of insect and host material under winter conditions, 10 indoor environmental chambers, three freezers and several refrigerators (including a fire-proof model for dangerous chemicals), four chain saws, one generator and a large amount of field forestry equipment, hardware tools, and general minor laboratory equipment.

- In the fall-winter of 1997-8, we acquired gas chromatographic equipment that allows for shunting fractions from one column to another for amplified analysis, and a considerable amount of analytical equipment needed by Dr. A. Kermode to conduct biochemical studies on the breakdown of conifer seeds fed on by seed bugs. In 1999 we upgraded our laboratory computing capability and replaced much of our inventory of worn-out multiple-funnel traps.

- In the spring of 1997, I entered into an agreement with Dr. Dai Jones of Pacific Cedar Industries (PCI) in Langley, B.C. for PCI to build and operate a 23 kg capacity steam distillation apparatus modelled after their 9-tonne stills for extraction of cedar oil from hog fuel. This "mini" still is used occasionally to extract the bark of various host and non-host trees for testing against bark and woodboring beetles, to determine if natural bark extracts could be cheaper and more competitive attractants and disruptants than blends of expensive synthetic chemicals.

IX. FINANCIAL SUMMARY

The following financial statement is unofficial, but I believe that it is accurate. It excludes all funding and expenditures for agriculturally-oriented research, and estimates with good precision the revenue and expenditures from 1 October 1998 to 30 September 1999, noting grants and contracts with start and end dates differing from the accounts in the NSERC CRD Grant package.

Expenditures exceeded revenue by $49,407.33, because the Chair was at peak activity level. This level will likely decrease somewhat as students graduate in 1999-2000, rectifying this imbalance.

A. REVENUE (1 October to 30 September, 1999, including accounts with end dates on 30 September 1999 and 30 March 2000)

NSERC CRD PACKAGE			
NSERC	$150,000.00		
Forest Renewal B.C.	75,000.00		
Industry, Direct Contribution	66,853.80		
Total		$291, 853.80	
FOREST RENEWAL B.C.			
Woodborers (#PA97511)	$147,390.00		
Seed bugs (#PA97510)	87,394.00		
Total		$234, 784.00	
OTHER GRANTS			
NSERC Research	$46,200.00		
Great, Industry	4,500.00		
Total		50,700.00	
TOTAL REVENUE			$577,337.80

B. EXPENDITURES

SALARIES AND BENEFITS			
Salaries	$322,351.96		
Benefits	28,736.71		
Total		$351, 088.67	

TRAVEL			
Field	$69,397.10		
General	8,788.72		
Total		78,185.82	
EQUIPMENT		51,163.00	
MATERIALS, SUPPLIES, ADMINSTRATION		146,307.64	
TOTAL EXPENDITURES			$626, 745.13

C. CURRENT FINANCIAL POSITION

Balance on 30, September 1998	$216,360.50		
Revenue, 1 October 1998-30 September 1999	577,377.80		
Total		$793,698.30	
Expenditures, 1 October 1998 - 30 September 1999		626,745.13	
BALANCE ON 30 SEPTEMBER 1999			$166,953.18